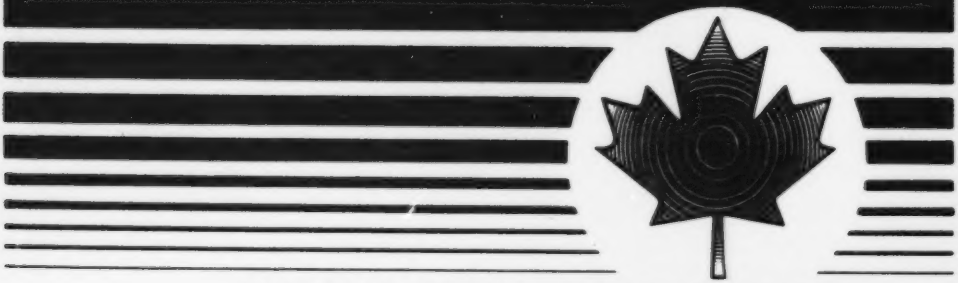
MODELS FOR ENERGY POLICY ANALYSIS: A SURVEY

Kenneth D. Frost, Gerard J. Protti and Gordon W. Douglas



CANADIAN ENERGY RESEARCH INSTITUTE

Client Research Report No. 81-1, July 1981
ISBN 0-920522-16-5

Models for Energy Policy Analysis: A Survey

Kenneth D. Foat and Gerard J. Protti
and
Gordon W. Douglas

ISBN-0-920522-16-5

CANADIAN ENERGY RESEARCH INSTITUTE
3512 - 33 STREET N.W.
CALGARY, ALBERTA
T2L 2A6
PHONE: (403)282-1231

PRICE $10.00

Lithographed in Canada by
Lawson Printing, Calgary, Alberta

July, 1981

The Canadian Energy Research Institute is a co-operative research organization sponsored by four parties, the federal Department of Energy, Mines and Resources, the Alberta Department of Energy and Natural Resources, the Private Energy Research Association (composed of corporate and individual members from oil, gas, coal, electrical, nuclear energy and pipeline companies) and the University of Calgary. The objectives of the Institute are to develop an economic research capability and to conduct studies that will assist industry and government in dealing with energy problems. The research program of the Institute is developed by a Board of Directors named by the sponsoring organizations. The content of the individual studies is, however, the responsibility of the authors.

LEGAL NOTICE

This report was prepared by the Canadian Energy Research Institute as an account of work sponsored by the Canadian Electrical Association, (CEA). Neither CEA, members of CEA, nor the Canadian Energy Research Institute, nor any person acting on behalf of either:

(A) Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

(B) Assumes any liabilities with respect to the use of, or damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

The views and opinions of authors expressed herein do not necessarily state or reflect those of the Canadian Electrical Association or of any of its members.

CONTENTS

FIGURES.....vii

TABLES.....vii

HIGHLIGHTS.....ix

ACKNOWLEDGMENTS.....x

EXECUTIVE SUMMARY.....1

CHAPTER 1 INTRODUCTION.....3

1.1 The Project.....3

1.2 The Purpose of an Economic Model.....4

CHAPTER 2 MODEL IDENTIFICATION AND CLASSIFICATION.....5

2.1 Identification Procedure.....5

2.1.1 General Criteria.....5
2.1.2 Information Sources.....9

2.2 Energy Model Classification Procedure.....10

2.3 Additional Comments.....12

CHAPTER 3 MODEL EVALUATION AND RECOMMENDATIONS.....15

3.1 Evaluation of Energy Demand Models and Components.....15

3.1.1 Specific Criteria for Evaluation.....16
3.1.2 Recommendations.....19

3.2 Evaluation of Energy Supply Models and Components.....21

3.2.1 Specific Criteria for Evaluation.....21
3.2.2 Recommendations.....23

3.3 Evaluation of Canadian Macroeconomic Models.....30

3.3.1 Specific Criteria for Evaluation.....30
3.3.2 Recommendations.....32

CHAPTER 4 FUTURE RESEARCH.....35

4.1 Detailed Model Assessment Method.....35

4.2 Cost Considerations.....37

4.2.1 Acquisition or Access Cost.....38
4.2.2 Conversion.....39
4.2.3 Development.....40
4.2.4 Data Collection.....40
4.2.5 Operation.....40
4.2.6 Maintenance and Refinement.....41

APPENDIX A: LIST OF PERSONAL CONTACTS.....45

APPENDIX B: BASIC STRUCTURAL METHODOLOGIES.....49

B.1 Equilibrium in a Spatial Network.....49

B.2 Equilibrium in a Translog and Variable Coefficient Input-Output Framework.....54

APPENDIX C: BASIC SOLUTION TECHNIQUES.....61

C.1 Mathematical Programming.....61

C.2 Econometrics.....63

C.3 Engineering Process Analysis.....64

C.4 Network Analysis.....65

C.5 Systems Dynamics.....65

C.6 Input/Output Analysis.....65

APPENDIX D: MODEL-SPECIFIC EVALUATION.....67

BIBLIOGRAPHY.....105

FIGURES

2.1 Schematic Representation of Energy/Economy Interaction.....10

3.1 Representative Reference Energy System.....25

3.2 Elements of an Energy Network.....28

B.1 Simple Network Methodology.....50

B.2 Illustrative Gas Network.....51

B.3 Elements of an Energy Network.....53

B.4 Supply-Demand Curve Representation.....56

TABLES

2.1 Classification of Energy Models.....13

3.1 Demand Model Characteristics Table.....17

3.2 Supply Model Characteristics Table.....22

3.3 Macro Model Characteristics Table.....31

HIGHLIGHTS

Technical change, environmental concerns, capital availability and increasing regulation are making electric power supply options more complex. Computer models are tools which can aid decision makers in assessing effects of such changes. Member utilities of The Canadian Electrical Association (CEA) are interested in obtaining an energy model system capable of meshing supply and demand relationships for all energy sources with a model of the Canadian economy. The system would be used to evaluate the effects of changes in energy costs, policies and technology on energy producers and distributors.

Model recommendations are based on a survey of more than 50 models. The general evaluation criteria included: model completeness, representation of energy demand or supply type, feasibility of physically acquiring the model, applicability to North American energy issues, and long-range planning capacity. Supply activities modelled in the system must account for primary energy production, conversion, transportation and distribution, nationally and locally. Demand activities must be capable of measuring the relative importance of important factors affecting national and provincial energy demand by type. The system must indicate the implications for the major provincial and national macro-economic indicators (inflation, employment, output and exchange rate) of alternative energy supply and demand paths.

The authors recommend that the following models be subjected to a formal assessment process:

(1) Energy Demand: (a) The DataMetrics Ltd. Energy Demand System (Calgary)
(b) Canadian Interfuel Substitution Demand Model (IFSDM); Energy, Mines and Resources (Ottawa)

(2) Energy Supply: (a) Time-Stepped Energy System Optimization Model (TESOM); Brookhaven National Laboratories (New York).
(b) Generalized Equilibrium Modelling System (GEMS); Decision Focus, Inc.; (Palo Alto)

(3) Macroeconomy: (a) The Informetrica Model Ltd. (TIM), (Ottawa).

The assessment process will require estimating the costs of: data collection, model conversion and extensions.

Acknowledgements

This research project spanned six months (July-December 1980) and was carried out by the following project team at the Canadian Energy Research Institute (CERI), in Calgary.

G. E. Angevine	Executive Director
G. W. Douglas	Economist
K. D. Foat	Economist
G. J. Protti	Senior Economist

We would like to thank the many individuals who provided assistance during the course of the study. In particular, we benefited from the cooperation and advice of the Canadian Electrical Association monitors, Victor de Buen (B.C. Hydro) and William Shelson (Ontario Hydro). The overall report was reviewed by Robert McRae (University of Calgary) and Fred Schweppe (Massachusetts Institute of Technology). Cor van de Panne, of the University of Calgary, reviewed Appendix C. Special thanks are due CERI staff members Shirley Ingstrup and Barbara Lees who were responsible for typing, and Eric Howling and Cathy Szata for research assistance.

EXECUTIVE SUMMARY

Computer models are tools which can aid the policy maker to assess the effects of changes in the decision-making environment. Our task in this project has been to survey computerized models which could be used by Canadian electric utilities to analyze the implications of change in energy markets and in government energy policies.

The demand side of such an energy model system must be capable of measuring the relative importance of the many factors which influence the national and provincial demand for all types of energy. The supply side must be able to take into account the production of primary energy resources, their conversion into various energy forms, and the transportation and distribution of these energy forms to consuming sectors and end uses--both nationally and regionally. The computer framework should also link the energy system relationships to key macroeconomic parameters such as employment, inflation, output, and the exchange rate. In this way, the implications for major provincial and national economic indicators of alternative energy supply and demand time paths and vice versa may be analyzed.

We identified and classified approximately fifty models which could meet at least a portion of the Canadian Electrical Association's requirements. We then compared and analyzed the individual models against specified evaluation criteria. As a general finding, a single model capable of meeting all of the requirements simply does not exist. However, we were able to recommend various models for the analysis of: (1) energy demand, (2) energy supply, and (3) the macroeconomy. We believe that these models could be integrated into a powerful analytical framework.

We recommend that the following models be subjected to a more formal and rigorous assessment process:

(1) Energy Demand: (a) The DataMetrics Energy Demand System
(b) Canadian Interfuel Substitution Demand Model (IFSDM)

(2) Energy Supply: (a) Time-Stepped Energy System Optimization Model (TESOM)
(b) Generalized Equilibrium Modelling System (GEMS)

(3) Macroeconomy: (a) The Informetrica Model (TIM)

In our opinion, these models are the most promising computer tools for energy policy and related technology impact analysis. It is not possible to recommend a single model in each category as being the 'best' because the necessary information on model capabilities and costs can only be acquired through in-depth model assessment which would involve detailed assessment of computer code and experimental simulations with each model. Because of this, we have conditionally recommended two other macro and two supply models to serve as alternatives should the preferred models prove unfeasible.

Besides the theoretical soundness of a modelling framework, one must consider and compare the costs involved. The initial acquisition cost of a model is only one of six cost elements we outlined. Other 'start up' costs would include data collection, computer code conversion, and model extension. Additional ongoing costs for the model system would be for operation and maintenance. Acquisition and operation costs are the only categories to which we could reasonably attach rough estimates. The other cost components can only be appraised with the benefit of an in-depth model assessment.

The Canadian electric power industry, as a major supplier of energy for residential, commercial and industrial uses, can be expected to grow prodigiously relative to its oil and gas counterparts. Given technological change, environmental concerns, capital availability issues and increasing regulatory constraints, electric power supply options are less clear cut than in the past. Because Canada's electric utilities co-exist within a complicated interdependent energy supply and demand system, computer tools to aid in the understanding of that system must reach beyond the confines of a direct description of electricity supply and demand. In this regard, the eclectic approach we have recommended would lead to a superior energy model system for Canadian energy policy and planning analysis.

Chapter 1
INTRODUCTION

Computer models are tools which can aid the policy maker and planner in the determination of the impact of change. Our task in this project has been to survey computerized models which could be used by Canadian electrical utilities to analyze the implications of change and contingent developments in the electricity market, other energy markets and the economy.

1.1 The Project

More specifically we interpreted the CEA modelling objectives to be threefold:

- to provide an additional input into all aspects of the utility planning process;
- to provide a means whereby the consequences of provincial and federal energy policy can be analyzed; and
- to provide an indication of the impact of future technological change for energy producers and consumers.

To accomplish this requires a computerized framework with the following broad attributes:

- a well-defined energy sector encompassing supply and demand relationships for all energy sources; and
- integrating links to a macroeconomic model to ensure that such issues as the long-run effects of energy prices on economic growth, and of new supply and demand technologies on the composition of economic activity are properly delineated.

These interpretations of CEA objectives have served to guide us throughout the project.

This study is a survey of energy models. Our analysis is based on our interpretation of the published descriptions, documentation and reviews of each model. It was not within our mandate to physically acquire any of the models for simulation or testing. Despite the

limitations of the approach used, we were able to determine the relative applicability of each model to the specific needs of the Canadian Electrical Association.

This study is structured as follows. Within Chapter 2, models with the potential for meeting various portions of the CEA objectives are identified and classified. In Chapter 3, model-specific evaluations are summarized and recommendations made. We have not hesitated to provide judgements in commenting on the various models, but readers should keep in mind that many of the issues raised can only be resolved by extensive testing and examination. The fourth and final chapter contains a discussion of the issues surrounding possible approaches to future research in this area.

Before proceeding further, it is useful to consider the role of economic models in decision-making processes.

1.2 The Purpose of an Economic Model

An economic model is merely a tool for bringing together diverse information in a way that provides insight into national or regional policy and decision problems. Economic markets such as those associated with energy are particularly difficult to specify in a modelling framework because they comprise many interacting production and consumption activities and frequently changing relationships.

Economic models are never used alone in decision-making roles. Rather, they are intended to clarify known relationships among economic variables and to direct the analyst's thinking to important but perhaps otherwise unforeseen consequences of those relationships. This is the same basic process that analysts and planners would attempt to pursue in the absence of economic models; models not only allow them to better organize their approach to problem solving but, more importantly, to analyze the interdependent relationships.

Chapter 2
MODEL IDENTIFICATION AND CLASSIFICATION

This chapter contains a description of the identification and classification procedure we utilized to define those models which have some potential for meeting Canadian Electrical Association requirements. Six general criteria were used to identify energy models. Of these, five were also applicable in identifying relevant macroeconomic models. The information sources utilized to identify the models are described and the models are classified according to their degree of specificity. The chapter concludes with additional comments on the identification and classification process.

2.1 Identification Procedure

2.1.1 General Criteria

All models are built for specific types of analyses. Every model builder achieves a certain degree of success in meeting that development objective. The matching of the CEA modelling objectives within an existing modelling framework is a most difficult exercise. The problems inherent in matching analytical tools with objectives often result in the construction of models 'from scratch'. However, while providing a model specifically geared to the goals of the sponsor, this approach would be both extremely costly and time consuming. For this reason, our task has been to determine whether or not existing models could possibly be utilized to meet the energy modelling goals of the Canadian Electrical Association and its member utilities. This research objective led us to the first of six criterion utilized for identifying models as feasible for the task.

Identification Criterion 1

> The model must be working or developed to a stage where it could be operational by the summer of 1981.

Thus models that are theoretically elegant but still in the early development stages have been excluded from this survey.

Energy models can be as disaggregated and specific as one wishes. For example, there are models which have been developed to facilitate choice among generating plant alternatives, oil reservoirs, fuel choice for a manufacturing process or other options. Because this survey does not encompass analysis of all models specific to every energy process or consumption activity, the following decision criterion reflecting a minimum level of economic activity and energy representation in a model was chosen.

Identification Criterion 2

A model must represent at least the following activity to be considered as a candidate model:

- market supply or demand of more than one energy source; or the
- complete market supply and demand aspects of at least one energy source.

Therefore, market sector models containing relationships describing supply or demand (or parts thereof) of just one energy source do not qualify. Nor do models depicting only a single consuming sector. For example, a model describing the demand for gasoline by the manufacturing sector would not qualify for further examination due to any one of the following reasons:

- it has no gasoline supply side;
- it deals only with the demand for gasoline and no other energy commodities; and
- it focuses only on the manufacturing sector's demand.

This identification criterion was necessary to keep the project within manageable bounds.

A related criterion deals with models which are extensions of broader modelling frameworks. For example, a model developer may have the capability to undertake analysis with a general energy demand and/or supply framework or to analyze more specific energy questions as described in the previous example. In this case there may be several more detailed submodels which are not physically linked to the general energy system model. To choose which of an organization's models to examine the following criterion was used.

Identification Criterion 3

> In those cases where organizations have models which tend to accomplish all of or a portion of the same tasks with differing degrees of specificity--the candidate models will be those which represent the level of aggregation closest to matching CEA objectives.

Another general objective of the Canadian Electrical Association regarding this project is to have an analytical framework which is capable of 'hands on' analysis or, at least, to have the ability to respecify equations and coefficients. This led to the following constraint.

Identification Criterion 4

> It should be possible to physically acquire the model or to make required structural modifications in order for the model to be identified as a feasible alternative.

The latter half of this criterion provides for models which are proprietary instruments of private consulting firms to be eligible for candidacy. Structural changes can be made to these models if one is a client of such a firm. There is a tendency for such arrangements to be relatively more costly than acquisition of a model for in-house use. Also, the probability of a model being used as a 'black box' is greater if it was developed and is owned outside the user organization. Nevertheless, there frequently are opportunities to utilize an efficient model system without having physical possession of it.

A fifth criterion ensures that all identified models concentrate on a North American economic structure and energy concerns. Many energy models are global or international in scope. The relevance of the issues (largely OPEC oil and gas) which these models focus on is peripheral to the objectives of the Canadian Electrical Association. Therefore

Identification Criterion 5

> Candidate models must reflect the institutional, economic and geographic structure of the North American energy industry and economy as their prime focus.

We have made an exception to this rule in identifying the major energy models of the Institute for Applied Systems Analysis in Austria. Its energy models are state-of-the-art European models, are readily available, and are generally focused on national issues.

A final restriction relates to the time horizon to which the energy model is oriented. The Canadian Electrical Association's guidelines indicated quite clearly that a long-range planning tool is required. As such,

Identification Criterion 6

> All short-term models (used in a less than 10-year time frame) to be rejected outright. Medium-term models (normally used for 10-20 year projections) to be acceptable only if easily and legitimately capable of extension beyond their normal forecast period.

The application of these criteria resulted in our identification of 44 candidate energy models.

In addition, we identified eight macroeconomic models which, if linked with an energy system, would have the potential to provide the energy/economy interaction necessary for a sound modelling system. These eight models and their sponsors are:

- AERIC; The Conference Board in Canada
- CANDIDE 2.0; The Economic Council of Canada
- CWEM; Alberta Research Council
- DRI; Data Resources Canada Ltd.
- Helliwell Macro; Univeristy of British Columbia
- RDX2; Bank of Canada
- TIM; Informetrica Ltd.
- TRACE; University of Toronto.

These models were identified for their capability to reflect the structure of the Canadian economy. The treatment of energy in these macro models was varied, ranging from virtually nil to detailed energy demand or energy system models. Most of the identification criteria was as applicable for the macro models as they were for the energy models.

2.1.2 Information Sources

To select energy models based on the identification criteria, we relied on three main sources of information.

- Previous model surveys

  For instance:

  - Survey of Research into Energy-Economy Interaction, U.S. Department of Energy, 1979
  - A Review of Energy Models, International Institute for Applied Systems Analysis, 1978
  - A Catalog of Energy Models, Energy Modeling Forum, 1978

- Computerized literature searches

  The purpose here being to provide an up-to-date listing of both published and unpublished references to energy modelling. This search encompassed the following databases:

  - Comprehensive Dissertations Index, containing abstracts of American and Canadian dissertations, 1961 to present, updated monthly;
  - Economics Abstracts International, consisting of abstracts of world-wide economic-related journal articles, reports and books, 1974 to present, updated monthly;
  - Energyline, which contains a multi-disciplinary range of energy topics from journals, conferences, and government publications, 1971 to present, updated bimonthly;
  - National Technical Information Service (NTIS), consisting of abstracts of all U.S. government sponsored research, 1964 to present, biweekly updates.

- Individuals with energy modelling expertise.

  This included discussions with in-house and contract consultants and various personal contacts with model surveyors and developers. Appendix A contains our list of such personal contacts.

2.2 Energy Model Classification Procedure

As an illustrative aide, consider first an extremely simplified representation of the major components of the energy system and its relationship to the rest of the economy.

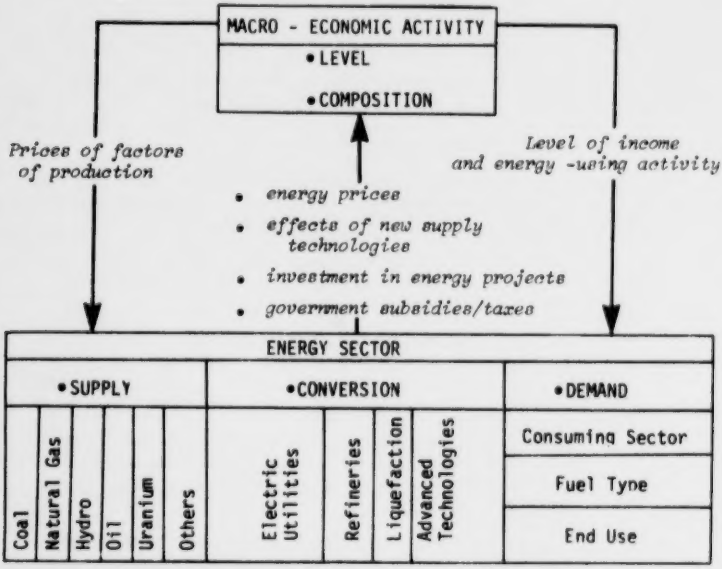


FIGURE 2.1: Schematic Representation of Energy/Economy Interaction

Given these considerations, the energy models identified in Section 2.1 were arbitrarily classified according to the scheme outlined below.

Energy System Models

These are models in which demand and supply relationships are endogenous (i.e., determined within the model) for more than one energy source.

The energy system is an array of interrelated markets that link alternative primary resources and conversion technologies to a variety of end uses and user types. The energy system approach to modelling focuses on the interactions of those energy supplies and demands that are most directly related to the major energy products and uses.

Any model endogenously calculating energy demand and supply should have some link to the overall economy, since it is the factor that is most important in determining the demand for energy. The link may be either explicit (as illustrated in Figure 2.1) or implicit (this implies that the level of economic activity is specified exogenously).

Energy Sector Models

These are models in which the demand or supply of more than one energy source is specified.

In relation to Figure 2.1, these models concentrate on one side only of the energy system and do not incorporate energy/economy interactions. This narrower focus generally allows energy sector models to be rich in technological detail.

A supply-side energy sector model normally includes some form of description of the conversion process from primary resources to end use energy form, although the level and composition of demand is user-specified. Demand side models generally take the supply of all primary resources and their conversion as given.

Energy Industry Models

These models encompass the supply, conversion and demand of one energy source.

As shown in Figure 2.1, the energy sector is organized into distinct energy industries: coal, uranium, electricity, and oil and gas. In general, these industries differ substantially with respect to structure.

Public utility regulation, field price regulation of gas, and oil price controls have distinctly different implications for model specification. Economies of scale and resource depletion affect

electric power, gas, oil, and coal differently, and in addition the industries differ in their geographic features and in the nature and intensity of competition.

Partly because of these structural anomalies, the quality and organization of available data also show important differences. Petroleum consumption data reflect the geographic organization and marketing channels of that industry, whereas electricity and gas consumption data are organized according to the main utility rate classes.

These differences encourage the development of individual industry models in an effort to capture the key attributes of various energy types.

Table 2.1 lists the candidate energy models classified according to such a scheme.

2.3 Additional Comments

Two sorts of general comments can be made with respect to our identified models. The first concerns the difficulties inherent in model classification and the second is related to the differences that still remain within a particular class.

In the first place, the classification procedure is not as cleancut as implied. Several sources of uncertainty and ambiguity can be identified:

- often insufficient documentation is available (we largely relied on published references)
- the 'moving target' dilemma often presents itself (models in the development stage are constantly evolving; two concurrent publications may thus contradict each other)
- models have frequently been partially re-specified, or extended for a particular application.

The models are therefore classified as we interpet their 'normal' configuration from published references.

Secondly, within each broad class a great deal of variability remains among individual models. This includes differences of the following kind:

TABLE 2.1: CLASSIFICATION OF ENERGY MODELS[a]

Energy System Models[b]	Energy Sector Models		Industry Models
	Supply	Demand	
The Canadian BALANCE Model	Alberta Energy Resources Allocation Model (AERAM)	Hotelbarics Energy Demand System	Appalachian Coal Market Model (ACM)
BALLOON	Brookhaven Energy System Optimization Model (BESOM)	Canadian Energy Demand Model (EMI)	CRA/EPRI Coal Market Analysis System (CMAS)
Elephant-Rabbit Model*	British Columbia Energy System Model (B.C. Hydro)	Canadian Interfuel Substitution Demand Model (IFSAM)	Coal and Electric Utilities Model (CEUM)
Canadian Exploy Model	Brookhaven Dynamic Energy System Optimization Model (BESOM)	Ontario Energy Demand System	Griffin Electricity Model
Canadian Welfare Equilibrium Model (CHEM)*	Bechtel Energy Supply Planning System (ESPS)	Ontario-Edmonds General Equilibrium Energy Demand Model*	Hackney-Pindyck Natural Gas Model (H-P)
Dartmouth College Energy Model	Generalized Equilibrium Modelling Systems (GEMS)	The Informetrica Model (TIM)	Regionalized Electricity Model (REM)
Integrated Forecasting Model (IFM)	Long-Term Energy Analysis Package (LEAP)		Electric Energy Supply Model (EESM)
Energy Technology Assessment Model (ETA-MACRO)*	Western Canada Energy Supply Model (Shome)		Total Energy Resource Analysis (TERA)
Fuller-Zinaba Model	Brookhaven Time-Stepped Energy System Optimization Model (TESOM)		
Integrated Model for Energy Policy Analysis (IEPA)			
Hopfilcan Model*			
The IEA Energy Simulation Model			
IIASA Energy Systems Program (ESP)			
Kennedy-Olsmayer Model*			
Long-Term Interindustry Transactions Model (LTIM)			
Midterm Energy Forecasting System (MEFS)			
PILOT Economic Energy Model*			
Bechtel Corporation Regional Energy System for the Planning Optimization of National Scenarios (RESPONSE)			
Resources for the Future/ Strategic Environmental Assessment System (RFF/SEAS)			
SRI-Gulf Energy Model			
Wharton Annual Energy Model (WHEM)*			

NOTE: This list does not purport to be exhaustive: other models met our identification criteria but were not included due to the fact that their methodology was better represented by models already on the list.

[a]The bold type denotes the acronym by which the model will henceforth be referred.
[b]The asterisk indicates those models with explicit energy/economy interaction.

- Underlying Structure

  These differences are especially notable in the larger energy systems. Appendix B examines specific issues with respect to the theoretical methodology.

- Analytical Technique

  Though not totally unrelated to the underlying structure, a wide range of methods may be invoked for actually solving the model. Appendix C describes the basic model solution techniques; mathematical programming, econometrics and engineering process analysis.

- Focal Point

  Depending on the original design purpose of a model, various energy forms or sectors may receive very different emphasis. Therefore, it is of overriding importance to evaluate any model only within the range of application it was intended to address.

Once models which fit our identif ation criteria were determined and classified, each was evaluated to sess its specific suitability for fulfilling the CEA objectives. The model evaluation results are discussed in the following chapter.

Chapter 3

MODEL EVALUATION AND RECOMMENDATIONS

This chapter contains our model evaluation and recommendations and is divided into three sections corresponding to the major (demand, supply and the macroeconomy) components of an energy modelling system as outlined in the previous chapter. To assess the various models requires that a consistent 'information set' be developed and logically considered. This descriptive information is composed of vital characteristics which together describe the basic nature of the model. The evaluation rationale is derived from the project mandate and our experience in energy modelling.

Therefore, each major section of this chapter, in turn, has two subsections. In the first, the information set and evaluation rationale are explained and a summary table is presented. Every model that we identified that has one of the three components in its makeup is included in the summary table.[1] The second subsection contains our recommendations regarding those models we consider to be most suitable for the Canadian Electrical Association's needs.[2] The entire chapter is supported by Appendix D which provides further information on the advantages, disadvantages, uses, and published commentary with respect to the identified models.

In general, we found that no single model or system of models is capable of completely meeting the needs and objectives of the Canadian Electrical Association. Each model has its own particular strengths and limitations. Nevertheless, we do feel that several different energy models could be combined to provide a detailed and powerful computer tool for energy policy analysis.

3.1 Evaluation of Energy Demand Models and Components

Of the total number of models we identifjed, 29 were either energy demand sector models or energy system or industry models with an endogenous demand side.

3.1.1 Specific Criteria for Evaluation

We identified six specific characteristics which were important for the evaluation of the energy demand models. Since many other features influential in our decision were not present in all the models surveyed, they were not easily placed in a summary table and, as such, have been included in the model-specific evaluations contained in Appendix D. The descriptive characteristics which provide the column headings in Table 3.1, and the criteria by which they were judged, are explained below.

1. Modelling Approach

In this context 'modelling approach' refers specifically to the empirical technique invoked to solve the model. The demand models surveyed rely on a wide variety of solution methods; the most common of which is econometrics.

Ideally what we were looking for was a hybrid econometric/process-analysis energy demand model which could incorporate behavioral factors with disaggregated technological characteristics and relationships. Historically, econometric models have stressed the importance of all energy prices and output or income as determinants of energy demand. Econometric demand models have been weak in the treatment of energy-using capital stock characteristics and non-price policy variables. Optimizing process models concentrate on disaggregated technological relationships, while lacking on the price and interfuel substitution side.

We also searched for a dynamic multi-equation model which would account for the differing characteristics of the short run (when the capital stock and its characteristics are fixed) and the long run (variability in capital stock). Static equilibrium and dynamic partial adjustment models are second-best treatments of the relationship of demand for energy and for its requisite capital in the short and long run.

2. Description/Application/Review

'Description' is defined as a minimum amount of publicly available documentation and material to allow for our process of evaluation. All of our identified models are adequately described for our purposes.

TABLE 3.1: DEMAND MODEL CHARACTERISTICS TABLE

Model Acronym	Modelling Approach	Description Application Review D/A/R	Spatial Aggregation (regions)	Forecast Period[a] (years)	Usual Periodicity (years)	Final Demand Aggregation By:[b] End Use	Fuel	Consuming Sector	Elasticities Own-Price	Cross Price	CEA Specific Suitability
BULLDOG	econometric	yes/yes/yes	1	100+	5	no	no	yes(4)	yes	yes	no
CERM	LP	yes/yes/yes	39	30	5	yes	yes(36)	yes(6)	yes	yes	no
CHEM-Energy	econometric	yes/no/no	1	40	5	no	yes(5)	yes	yes	yes	no
Dartmouth	accounting	yes/yes/yes	1	20+	2	no	yes(3)	yes(4)	yes	yes	no
DataMetrics	econometric	yes/yes/no	7	15+	1	yes	yes(9)	yes(3)	yes	yes	yes
DRI	econometric	yes/no/no	7	25	1	yes(25)	yes(14)	yes(5)	yes	yes	no
ETA	econometric	yes/yes/yes	1	70	5	no	yes(2)	no	yes	yes	no
Explor	I-O	yes/yes/no	1	20	5	no	yes(5)	yes(5)	no	no	no
Fuller-Zlomba	econometric	yes/no/no	2	45	5	no	yes(5)	yes(4)	yes	yes	no
Griffin	econometric	yes/yes/no	1	10	1	no	yes	yes(2)	yes	no	no
Hoyllicza	econometric	yes/yes/yes	1	30	1	no	no	yes(2)	no	no	no
IEA	accounting	yes/yes/no	1	50+	10	no	yes(4)	yes(3)	no	no	no
IEPA	econometric	yes/yes/no	8	20+	1	no	yes(6)	yes	yes	yes	no
IFN	econometric	yes/yes/no	1	20	1	no	yes(7)	yes(4)	yes	yes	no
IFSDM	econometric	yes/yes/no	7	20+	1	yes(10)	yes(17)	yes(7)	yes	yes	yes
IIASA (MEDEE)	process	yes/yes/no	1	50	5	yes	yes(6)	yes(3)	no	no	no
Kennedy-Mieneyer	econometric	yes/yes/yes	1	30	1	no	yes	yes(5)	no	no	no
LITN	econometric	yes/yes/yes	1	30	1	no	yes	yes(5)	yes	yes	no
MEFS	econometric	yes/yes/no	10	15	1	yes	yes(7)	yes(4)	yes	yes	no
N-P	econmitric	yes/yes/yes	40	15	1	no	yes	yes(3)	yes	yes	no
Ontario	econometric	yes/no/no	1	-	1	yes(20)	yes(7)	yes(5)	yes	no	no
PILOT	I-O	yes/yes/no	1	40+	5	no	yes(5)	yes	yes	yes	no
Reistar-Edmonds	LP/I-O	yes/no/yes	1	25+	-	no	yes(4)	no	no	no	no
REM	econometric	yes/yes/yes	9	25	1/2	no	yes	yes	yes	yes	no
RFF/SEAS	I-O	yes/yes/no	1+	50	10	no	yes	yes	yes	yes	no
SRI-Gulf	LP/econ.	yes/yes/yes	8	50	5	yes	yes	yes	yes	yes	no
TERA	econometric	yes/yes/no	1+	20	1	yes	yes	yes(4)	yes	yes	no
TIM - Energy	econometric	yes/yes/no	1	20	1	no	yes(6)	yes(3)	yes	yes	no
WAEN	I-O/econ.	yes/yes/yes	1	20	1	yes	yes	yes	yes	yes	no

[a] A dash (-) means that the 'usual' model forecast period or periodicity is unknown.

[b] Numbers in brackets refer to number of end uses, fuels, sectors specified in the model.

'Application' is defined as a publicly available detailed description of the use of a model for the purposes for which it was developed. We have made every attempt to uncover and acquire any relevant model applications.

'Review' is defined as an independent model assessment of the type described in Section 4.1. Model surveys which simply describe the contents of various models are not reviews. Given this definition, no Canadian energy model of any kind has ever been publicly reviewed. This is a serious drawback to Canadian energy models and one specialized area which requires considerable upgrading in this country.

In terms of our criteria for model evaluation it is intuitive that the more often that a model has been applied and reviewed, the greater the probability that the model's logic has been validated and verified.

3. Spatial Aggregation

We define spatial aggregation as the number of distinct geographical regions that a model normally includes. Some level of disaggregation is essential in the Canadian context due to the locational variation between energy producers and consumers. Therefore, the applicability and costs of conversion of existing regionally articulated Canadian models are significantly more favourable than models not regionally disaggregated.

4. Forecast Period and Periodicity

Forecast period refers to the number of years a model normally simulates; periodicity indicates the frequency of time-steps within the forecast horizon.

According to our mandate, a model should be capable of annual simulation through at least a 20-year horizon.

5. Final Demand Aggregation

Energy demands may be defined by end use, fuel and/or consuming sector. Some models are highly aggregated and describe total energy demand by two sectors in the economy. Other energy demand models are highly disaggregated by end use, fuel and consuming sector.

The higher the degree of disaggregation, the more precise the policy and technological analysis undertaken with the models can be.

For purposes of this project, then, a model had to have some disaggregation by fuel and consuming sector (the more the better) to be recommended. If a model was disaggregated by end use this was a positive attribute since the implications of technological change are best analyzed with end use demand description.

6. Elasticities

All energy demand models project demand based on some income, output, or activity variable. However, to be relevant to almost any analysis, and certainly, for the objectives of this project, an energy demand model must have a built-in sensitivity to energy prices. Price sensitivity is termed elasticity, and there are two main types. 'Own-price elasticities' of demand indicate the expected percentage change in the quantity demanded of a certain form of energy as a result of a one percentage change in the price of that same form of energy. 'Cross-price elasticities' illustrate the expected percentage change in one type of energy demand resulting from a one percentage change in the price of an energy complement or substitute.

Some models only have own or cross-price elasticities for some of the fuel types and consuming sectors they consider. In our summary characteristics table we have only indicated whether or not a model has some elasticities or none. Clearly the greater the number of elasticity relationships considered in a model the more useful it is likely to be for policy analysis.

3.1.2 Recommendations

As a general observation, we found Canadian energy demand models to be equal to and in some cases more sophisticated than U.S. demand models. There is really very little to choose between the better U.S. and Canadian demand models on the basis of the evaluation critera. That is, the cost savings from using Canadian models in this area would outweigh any perceived theoretical advantages from adopting a U.S. framework. Therefore, we are recommending two Canadian models which would not require 'Canadianization' or collection of a new data set. The models are:

- DataMetrics Energy Demand System, DataMetrics Ltd., Calgary, Alberta
- Canadian Interfuel Substitution Demand Model, Energy, Mines and Resources Canada, Ottawa, Ontario.

The DataMetrics Energy Demand System is a group of proprietory models developed under the direction of G. C. Watkins and E. R. Berndt. The models can be physically acquired, although the exact cost is presently unknown. The second best approach to working with this system might be to not acquire the source code of the models but to have the ability to change functional form and estimated parameters arranged as part of a contract with DataMetrics Ltd. The DataMetrics system generally meets and surpasses all of the specific evaluation criteria listed above. In addition, it has an excellent data base, a superior functional form, and the capability to be disaggregated further for more detailed sectorial analysis. Although the model has been built for a particular client, much of its documentation and results were included in a research submission to the National Energy Board, and thus have been subject to public scrutiny.[3] Its modelling weaknesses (in relative terms) are in the transportation and utility fuel demand sectors.

The Canadian Interfuel Substitution Demand Model (IFSDM) is well known. A significant advantage for this model is the fact that the acquisition cost is known to be minimal. The model is presently being used in a number of provinces and different applications. It is the model that has come closest to actual public review in Canada, in fact, a proprietary review of this model has recently been completed.[4]

The IFSDM has a high level of demand disaggregation and an extensive supporting data set. Moreover, it is relatively easy to operate. Its major weaknesses (again in relative terms) concern the inadequate handling of capital-energy substitution and the lack of regional disaggregation in the share equations. In addition, it was estimated in 1978 and is correspondingly out of date.

A relative comparison of DataMetrics and IFSDM would, in our opinion, suggest that the former is stronger in theoretical structure and functional form. The latter has an advantage over DataMetrics in acquistion cost, degree of demand disaggregation, software, and (possibly) quality of documentation.

Ultimately, the final choice between these two possibilities may rest on the analysis of all the costs to be incurred in acquiring, developing and operating a model system. Cost issues are considered in the next chapter. Suffice to note here that relative costs cannot be ascertained without a significantly more detailed model assessment than has been possible in this survey project.

In summary, we recommend that EMR's Interfuel Substitution Demand Model be acquired and subjected to hands-on analysis. In addition, we would also recommend that extensive negotiations and discussions with DataMetrics be undertaken to study that model's structure and determine all the relevant costs of future CEA operations with that system.

3.2 Evaluation of Energy Supply Models and Components

Of the total number of energy models identified, 38 were either energy supply sector models, or energy system or industry models, with an endogenous supply side.

3.2.1 Specific Criteria for Evaluation

The descriptive characteristics 2, 3 and 4, entitled Description/Application/Review, Spatial Aggregation, and Forecast Period and Periodicity, which were explained earlier for demand models, were identical for our examination of energy supply models. Four additional specific criteria for the evaluation of energy supply models were also used. These criteria are defined below, and their application to each model is summarized in Table 3.2. As in the case of the demand models surveyed, we found that the advantages and disadvantages of each model were often unique. Items not common to all the models, and therefore excluded from the summary table, were included in the model-specific evaluations of Appendix D.

1. Modelling Approach

There are several analytical methods by which the required technical and ongoing details of an energy supply-side may be embodied in a model system. The most common modelling approach in our recommended models is the linear programming technique which is most often selected because of its efficiency in solving large problems defined by a series of simultaneous equations. Other approaches are accounting, engineering process, input-output, system dynamics, and econometrics. Generally, accounting, input-output and econometric techniques are not particularly well suited to modelling the technical processes of energy supply because they are not optimization techniques.

2. Technological Detail

Two aspects are relevant in this regard: the model should contain comprehensive quantitative descriptions of existing supply

TABLE 3.2: SUPPLY MODEL CHARACTERISTICS TABLE

Model Acronym	Modelling Approach	Description Application Review D/A/R	Spatial Aggregation (regions)	Forecast Period (years)	Usual Periodicity (years)	Technological Detail	Endogenous Primary Resource Supply Functions	Electricity Sector Specifics	CLA Specific Suitability
ACH	OP	yes/yes/no	9	40	5	yes	yes	no	no
AERAM	LP	yes/yes/no	1	15	5	yes	partial	no	no
B.C. Hydro	LP	yes/no/no	1	-	1	yes	no	yes	cond.
BALANCE	LP	yes/yes/no	1	50	5	no	no	no	no
BESOM	LP-static	yes/yes/yes	1	-	-	yes	no	yes	no
BULLDOG	LP	yes/yes/yes	1	100+	5	yes	yes	partial	no
CEUM	LP-dynamic	yes/yes/yes	30	30	5	yes	yes	yes	no
CHAS	LP/econ.	yes/yes/no	13	25	1	yes	yes	no	no
CHEM	LP-dynamic	yes/no/no	1	40	5	yes	yes	yes	no
Dartmouth	sys. dyn.	yes/yes/yes	1	20+	2	no	no	yes	no
DESOM	LP	yes/yes/yes	1	45+	5	yes	no	yes	no
EESM	LP	yes/no/no	4	30	5	no	no	yes	no
Elephant-Rabbit	prod. fn.	yes/yes/yes	1	-	-	no	no	no	no
ESPM	accounting	yes/yes/yes	14	20	1	yes	no	yes	no
ETA	LP	yes/yes/yes	1	70	5	yes	yes	partial	no
Explor	1-0	yes/yes/no	1	20	5	no	no	no	no
Fuller-Ziemba	LP	yes/no/no	2	45	5	yes	partial	partial	no
GEMS	process	yes/yes/yes	1+	50	5	yes	yes	yes	yes
Griffin	econometric	yes/no/no	1	10	1	no	no	partial	no
Hoylicza	econometric	yes/yes/yes	1	30	1	no	no	no	no
IEA	accounting	yes/yes/no	1	50+	10	partial	no	no	no
IEPA	accounting	yes/yes/no	1	20	1	no	no	no	no
IFM	process	yes/yes/yes	1	20	1	yes	yes	partial	no
IIASA (MESSAGE)	LP	yes/yes/no	10	50	5	yes	yes	yes	no
Kennedy-Mansour	econometric	yes/yes/yes	1	30	1	partial	partial	no	no
LEAP	process	yes/yes/yes	1+	50	5	yes	yes	partial	no
LITH	econometric	yes/yes/yes	1	30	1	partial	no	no	no
MEFS	LP	yes/yes/no	7+	15	5	yes	yes	yes	no
M-P	econometric	yes/yes/no	18	15	1	yes	yes	no	no
PILOT	LP-dynamic	yes/yes/yes	1	40+	5	yes	yes	partial	no
REM	process	yes/yes/yes	9	25	1/2	yes	no	yes	cond.
RESPONS	LP	yes/yes/no	16+	-	5	yes	no	partial	no
RFF/SEAS	1-0	yes/yes/no	1+	50	10	partial	no	no	no
Rouse	LP-static	yes/no/no	8	-	1	no	yes	partial	no
SRI-Golf	process	yes/yes/yes	1+	50	5	yes	yes	yes	no
TERA	process	yes/yes/no	1	20	1	yes	yes	no	no
TESOM	LP-dynamic	yes/yes/yes	1	20	1	yes	yes	yes	yes
WAEM	econometric	yes/yes/yes	1	20	1	yes	yes	yes	no

technologies; and, the model should have the capability to incorporate into the decision mechanism any new supply technologies economically feasible within the planning horizon.

3. Endogenous Primary Resource Supply Functions

The inclusion of an explicit representation of primary resource supply provides a vital feedback mechanism between relative resource prices in the economy and supplies expected to be available to meet demands. A price-responsive supply function, then, corresponds to the price sensitivity ideally found on the demand side. Such an inclusion is one method for a model to internally equilibrate energy demand and supplies over all prices. If the supply of primary resources is determined outside the model, this means that the entire supply side is not as price responsive as it ought to be.

4. Electricity Sector Specifics

Because of the orientation of the ultimate users of the selected system, it is essential that some minimum level of detail of the electricity generation process be represented. This seems like a reasonable enough expectation but many models treat the electricity sector too simplistically. Ideally, we were looking for detail with regard to economic dispatch and system expansion.

The degree of specificity is somewhat less important with regard to other energy sources as their main interaction with electricity occurs on the demand (inter-fuel substitution) side.

3.2.2 Recommendations

The last seven years have seen the United States engaged in an extensive modelling program which has resulted in a proliferation of supply-related models. These models are generally characterized by the minimization of the cost of supply to various end uses from all energy conversion processes and primary resources, with energy demand being pre-specified or examined external to the models.

In general, Canadian energy supply models lack the level of technical precision and sophistication which have evolved in the United States. This is unfortunate since we believe the supply component to be by far the most important single factor in a complete energy modelling system. Our recommendations focus on two United States supply oriented models which we believe to be the most sophisticated approaches in this field.

The recommended models are:

- Time Stepped Energy System Optimization Model (TESOM)
  Brookhaven National Laboratories
  New York

- Generalized Equilibrium Modelling System (GEMS)
  Decision Focus, Incorporated
  Palo Alto, California

The Time-Stepped Energy System Optimization Model (TESOM) incorporates a sequentially-solved series of linear programs (LP), one for each representative time period, with control equations used to smooth the intertemporal transitions. The model was developed for the quantitative evaluation of national energy technologies and policies within a dynamic systems framework. It is designed to examine inter-fuel substitution (with an appropriate demand side and energy/economy link) in the context of time-dependent constraints upon the availability of competing resources (stocks) and technologies and their associated costs.

TESOM is structured around Brookhaven's Reference Energy System (RES), a specialized format for representing the detailed technological structure of the energy system along with resource depletion and associated environmental emissions. The RES is a network representation of the flow of energy from resource extraction, through all intermediate conversion processes, to the satisfaction of final energy service needs (e.g., space heating, air conditioning). The RES provides a complete and thermodynamically consistent energy accounting system, in physical units, for energy flows through energy conversion devices; the extraction or importation of primary energy resources and products; refining and the various stages of energy conversion, transportation, distribution, and storage; and consumption of fuels and electricity by end-use technologies corresponding to particular energy service demands. Within the RES, emphasis is placed on the comprehensive technological structure relating the energy flows which enter the system (e.g., oil) to the nonsubstitutable, functional energy services which are the final products of the flow (e.g., process heating). A sample RES is shown in Figure 3.1.

The time-stepped model optimally allocates energy resources and products and selects the optimal mix of fuels, conversion and end-use demand technologies according to selected energy, environmental, or economic criteria (usually least cost) to satisfy a set of energy service demands.

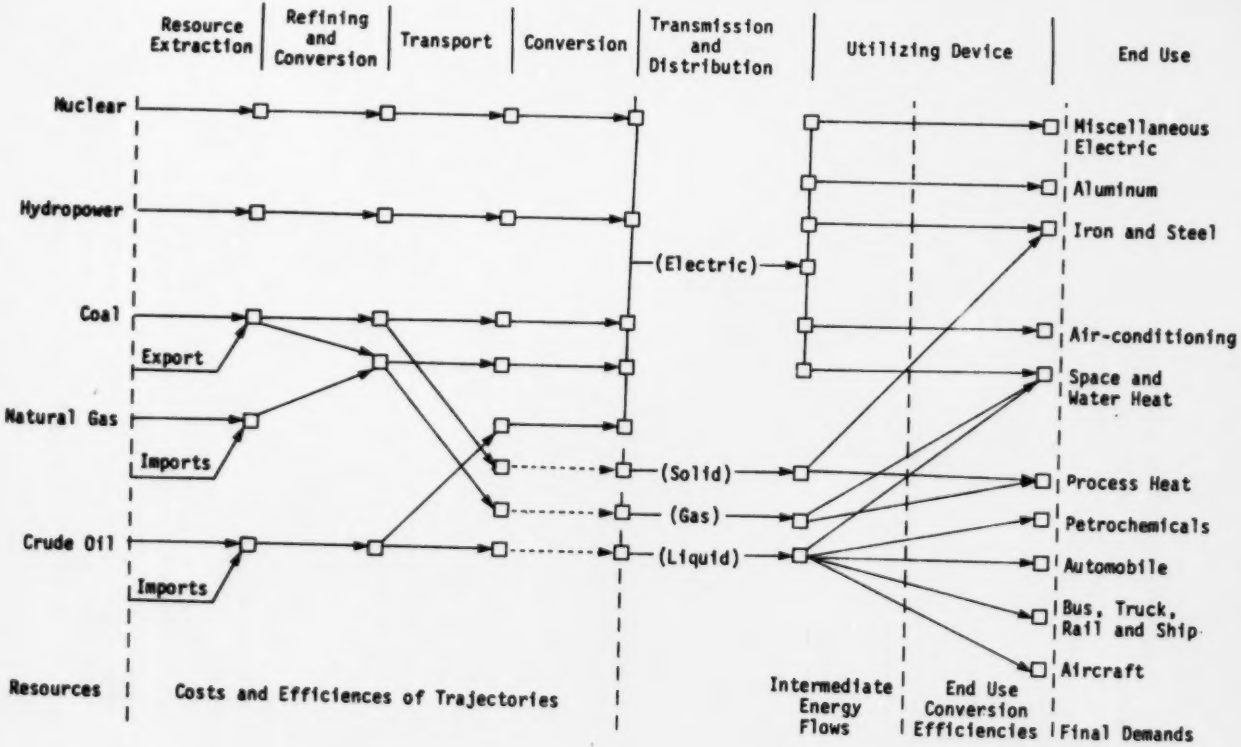


Figure 3.1: Representative Reference Energy System

TESOM exhibits the many advantages of BESOM and DESOM as listed in Appendix D, while incorporating significant improvements. TESOM differs in a number of ways from the clairvoyant-type energy system linear programming models whose characteristics are described in Appendix C and which are amply represented in our identified energy supply models.

- The most fundamental difference is in the treatment of 'information' about the past, present, and future. TESOM performs a sequence of single-period optimizations based on past decisions, present needs, and, optimally, expectations about the future prices of resources. Clairvoyant-type models use all of the information about the past, present, and future in one optimization to determine the 'best' strategy for the entire time horizon. An important implication of the clairvoyant-type decision-making is that all system shocks or 'surprises' such as oil embargoes or energy price jumps are foreseen, and the patterns of energy use are altered in anticipation of these disruptions. Since TESOM cannot anticipate future circumstances, it is possible to force the model to respond to an unexpected system shock at any point during the time frame.

- TESOM generates a separate linear program for each time period in a scenario, but they all tend to be of moderate size and are easily solved. A clairvoyant-type model optimizes only one LP for a scenario, but the more time periods involved, the larger the LP size and the longer it takes to solve.

- Because of its stepwise approach, TESOM is able to easily incorporate a dynamic market penetration algorithm to adjust, at each step, an optimistic penetration level for each technology into a penetration upper bound more in line with the developing scenario (it avoids the 'all or nothing' characteristic of most linear programming models). A market penetration smoothing algorithm can be incorporated into clairvoyant-type models, but this requires an iterative and, therefore, expensive solution procedure.

- TESOM has an excellent electricity sector formulation incorporating all the essentials of capacity expansion, generation and transmission of electricity.[5] Special features include a working capability in analysis of distribution, by-product heat, time-differentiated loads and alternative price structures.

As with most useful models, TESOM is in a continual state of evolution. Brookhaven Institute personnel are considering the following possible enhancements to the model.

- Multi-regional operation of the model.
- Greater detail in defining the conversion technology of oil refining.

TESOM may be acquired at minimal cost since its development has been sponsored by federal (U.S.) funding. Its biggest disadvantage would be the relatively high initial data collection cost needed for Canadian adaption.

GEMS is also a self-contained energy supply modelling system. GEMS is not so much one particular model, but more an approach to modelling structurally-oriented engineering-economic energy model systems.[6] The GEMS model structure is similar to the network representation of TESOM, as is the dynamic optimization procedure employed.

The structure of a Generalized Equilibrium Model of the energy sector of an economy shows, for example, the flows of all forms of energy from resources in the ground through various stages of production, transportation, conversion to other forms such as electricity, transmission, distribution, and end-use conversion to usable forms of energy or energy services such as electromechanical drive or heated dwellings.

This detail is achieved through using a hierarchical network system whose nodes represent individual market activities or industrial processes, each characterized by a generic technology. Within a node the construction of capital facilities is distinguished from operation and, in addition, changes in the design of facilities occur over time in response to price changes. See Figure 3.2 for a representative energy network.

Like TESOM, the GEMS solution methodology combines the advantages of mathematical programming optimization with those of simulation. In other words, iterative optimization techniques are utilized within a detailed structural simulation model.[7] Unlike TESOM though, GEMS allows a different optimization to be performed for each party represented in the model; no overall objective function required. The general effect of the GEMS analytical technique is to allow for a very high degree of simultaneity, while solving for each successive time period. The dynamic capabilities of the generalized equilibrium methodology are essential in modelling capital-intensive industries and

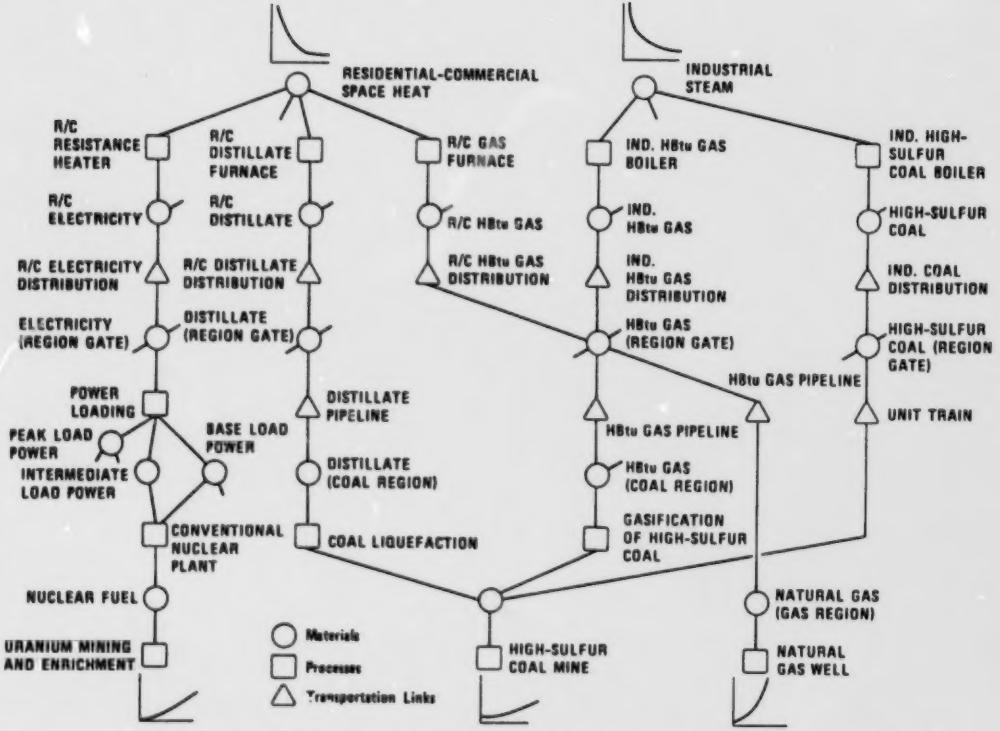


Figure 3.2: Elements of an Energy Network

industries that utilize nonrenewable resources or are undergoing substantial technological change.

The computer software to implement GEMS has been developed at Decision Focus Incorporated. The concensus is that the software package is state-of-the-art, encompassing model-oriented data base management systems and new modelling languages for the specification of model structure. The software is of such importance to this system that it cannot be disassociated for evaluation purposes.

The current frontiers in GEMS methodology involve characterizing uncertainty, monopoly and cartel behavior, and energy/economy interactions.

In recommending that a closer look be taken at the GEMS methodology, we are again stipulating a two-stage procedure; both stages necessarily proceeding with the cooperation of Decision Focus Incorporated:

- an in-depth structural investigation to ascertain the relative merits of the model and its associated software
- detailed negotiations with that consulting firm on the structural modifications and costs that would be required to apply a prototype GEMS in the Canadian context.

In addition to these main recommendations on the supply side, we suggest two models found in Canada be acquired as 'support' systems. These are:

- B.C. Hydro Energy Model
  B.C. Hydro
  Vancouver, B.C.
- Regionalized Electricity Model
  Canadian Energy Research Institute
  Calgary, Alberta

The B.C. Hydro model is a linear programming representation of the B.C. energy system. It is primarily electricity-oriented and represents a good LP framework that is already applied (this is particularly noteworthy since the system is hydraulically oriented).

The Regionalized Electricity Model (REM) is the Canadian version of a U.S. engineering process/econometric model which simulates the supply, demand and regulatory components of the electricity

industry. REM is being extensively used in the U.S. by the Electric Power Research Institute and the Edison Electric Institute to examine regional power planning questions.

Since both of these models are electricity-oriented, and are operational with Canadian data, either might serve as an acceptable and less costly substitute for specific components of TESOM and GEMS. Both models are available at low acquisition cost.

3.3 Evaluation of Canadian Macroeconomic Models

3.3.1 Specific Criteria for Evaluation

Certain evaluation criteria which were applied to both energy demand and supply models were also relevant for macroeconomic models. These are Description/Application/Review, Spatial Aggregation, and Forecast Period and Periodicity, as defined in Section 3.1.1, above. Four additional evaluation criteria specific to the selection of an appropriate macroeconomic framework are discussed below and summarized in Table 3.3.

1. Modelling Approach

All of the macroeconomic models examined are estimated econometrically. They assume that past history is relevant to the future and that the historical behavioral relationships remain stable through time. A 'Keynesian' model is demand oriented, that is, economic activity varies in response to expenditure flows in the economy. Such a model does not completely specify the interaction of supply and demand for primary factors of production. A 'neoclassical' model examines both supply and demand behaviour, emphasizing the role of relative prices in determining supply, production and long-term economic growth.

2. Input-Output Table

A macroeconomic growth model (which projects the level of economic activity over time) may or may not have an associated input-output structure (which would indicate the composition of economic activity at any point in time).

More specifically, an input-output table is a statistical summary of inter-industry transactions reflecting the interdependence of economic activity. A model with a 'static' input-output table has fixed coefficients and assumes that the technology of production

TABLE 3.3: MACRO MODEL CHARACTERISTICS TABLE

Model Acronym	Modelling Approach	Description Application Review D/A/R	Input-Output Table	Energy Model Links	Spatial Aggregation	Size	Forecast Period (years)	Periodicity	CEA Specific Suitability
AERIC	Keynesian	yes/no/yes	static	limited	national/ provincial	medium	2 - 5	quarterly	no
CANDIDE 2.0	Keynesian	yes/yes/no	static	limited	national	large	10	annual	no
CNEM	neo-classical	yes/no/no	dynamic	yes	national	large	100	quinquennial	cond.
GRI	Keynesian	no/no/no	static	yes	national/ some provincial	medium	10	annual	no
Helliwell	Keynesian	yes/no/no	no	yes	national	small	-	annual	cond.
RDX2	Keynesian	yes/yes/yes	no	no	national	medium	5	quarterly	no
TIM	Keynesian	yes/yes/no	static	yes	national/ some provincial	large	20	annual	yes
TRACE	Keynesian	yes/yes/yes	no	no	national	medium	20	annual	no

remains unchanged, that is, output is produced using fixed proportions of materials and factors of production. A 'dynamic' input-output table takes account of the interrelationship of current and past output and, in particular, the creation of capital stock. In the latter, technological progress can occur; the coefficients are variable so that input proportions, into the production process, change.

Obviously a dynamic I-O configuration is preferable, although this feature, because of the inherent simultaniety, limits model size and makes the structure considerably more complicated.

3. Model Size

In referring to the size of models the term 'small' is used for models of less than one hundred variables; 'large' for models of greater than two thousand variables; and 'medium' for anything in-between. Normally, the larger the model the greater the data collection cost.

4. Linking Capability with Energy System

A preferred macro model is one with which linking with the energy supply and demand models requires minimal changes to the structure of the model.

Two kinds of linkage are possible between a macro model and an energy model. A hard link would place all models in the same software framework so that all equations could be solved simultaneously. A soft link would take the outputs of one model to use as inputs to the others and subsequently vice versa if desired. This process would be repeated several times as required to attempt to achieve convergence. The ultimate objective for a CEA system would ideally be a hard link between component models in order that all feedback mechanisms could be suitably captured.

3.3.2 Recommendations

Canadian macro models are also well behind their American counterparts. The adaptation of one of these for Canada though would be a massive undertaking; so serious consideration was given just to existing Canadian models. After examining the eight identified Canadian macro models, we have concluded that none are ideally suited for use by the CEA. With this qualification in mind, we will briefly discuss the merits of the better alternatives.

The Informetrica Model (TIM) is preferred. The model was built by an Ottawa-based economic research firm, in the period 1976-1979. It is a reformulation of early versions of the Economic Council of Canada's CANDIDE Model. The model has 5,083 variables of which 952 are exogenous and 740 are stochastic. The model is based on the National Accounts and is a Keynesian, demand-oriented model. A static input-output table is incorporated which generates industry outputs and prices for the model. TIM contains an energy demand submodel with energy supply being exogenous. Supply and demand equate via residual balancing items such as oil imports. Spun off from TIM is a provincial construction model which provides forecasts of indicators such as gross provincial product, housing starts, households and non-residential construction investment for each province.

The use of a static input-output model is a serious flaw, for it fixes technology at the 1971 level. The assessment of changing technology in energy use then becomes most difficult. Coefficient adjustments in the model can be made but the results at best would be crude.

Two models worth taking a hard look at are currently under construction. CWEM, the Canadian Welfare Equilibrium Model, is being adapted to Canada by the Alberta Research Council and the Alberta Department of Energy and Natural Resources.[8] It takes a neoclassical growth model approach and incorporates a dynamic input-output table. These features are conducive to analyzing long-run problems in which technological change is important. Futhermore, the model is designed to ensure that energy-economy interactions are well articulated.

The second is being built by John Helliwell of the University of British Columbia and Robert McRae of the University of Calgary. This model has the virtue of being an easily manageable size, having only about 50 equations. It emphasizes the role that energy plays in the economy, so that its relatively small size may not inhibit effective linking with energy supply and demand models. It is designed to link with the Helliwell energy system model and will be publicly available.

These two latter models appear promising from a theoretical point of view and they will warrant further examination when they become operational. If the models meet design specifications and become available in a timely fashion either one may be more suitable than TIM for CEA purposes. At this time, they cannot be unconditionally recommended due to their 'incomplete' status.

Footnotes

[1]For example, many energy models treat all energy demands as exogenous, that is, demands are determined, external to or outside of the model boundaries. Therefore these models do not have an endogenous demand side and would not be included in the energy-model demand characteristics summary table. On the other hand, an energy system model endogenously calculating both supply and demand, would be evaluated under each of those respective headings. This sort of dichotomy was undertaken because often one component within a particular model is of superior quality.

[2]This is not to imply that the recommended models are 'best' for all purposes: the selection may well have been different had the CEA objectives been different.

[3]"Projections of Energy Demand Using a Modelling Approach, 1980-1990," DataMetrics Limited (prepared for NOVA), September 1980.

[4]"An Assessment of the Department of Energy, Mines and Resources Model of Energy Demand," DataMetrics Limited (prepared for NOVA), December 1980.

[5]It should be pointed out that, with respect to the electricity industry, earlier versions of TESOM (namely BESOM and DESOM) were primarily oriented towards thermal systems.

[6]Historically, the development of first, the SRI-Gulf model, and eventually what came to be known as the GEMS methodology, has been a fifteen-year effort by many sponsoring organizations and contributing individuals. It is currently the fastest growing modelling approach in North America. For instance, five years ago only about five modellers were actively involved with generalized equilibrium models and research, today there are over 100. To date about a dozen major GEMS models of energy systems have been constructed by various user groups.

[7]Simulation differs from generalized equilibrium modelling in that there is lack of an explicit optimization capability in simulation models. Eliminating the optimization capability removes the simultaneity between past, present, and future decisions and allows a simpler algorithm that solves each time point one at a time, starting with the first and progressing in order to the last time period of the model.

Optimization models differ from generalized equilibrium models in that it is usually necessary to restrict the models' assumptions and level of detail greatly in order to satisfy the theoretical and algorithmic requirements of the methods.

[8]The predecessor of this effort is the PILOT model developed at Stanford University.

Chapter 4
FUTURE RESEARCH

Our survey of computerized economic models on behalf of the Canadian Electrical Association did not reveal a clearly superior model or model system. In our opinion, any combination of the models we have recommended could, in due course, meet the main objectives of the Association. However, the selection of the 'best' approach can only be accomplished after a much more detailed assessment of the models.

In this chapter, we briefly outline the nature of the detailed investigative process required to assess the recommended models. That stage of the research would require analysis of both the capabilities and the relative costs of those models. This chapter consists of two sections corresponding to these issues.

4.1 Detailed Model Assessment Method

This study has, through an examination of the published literature describing, assessing and reviewing energy models, recommended viable modelling approaches which could meet the objectives of the Canadian Electrical Association. The intimate knowledge of the models required for final selection can only be acquired through in-depth assessment.

In-depth assessment has two main components:

- determination of a model's logic structure and identification of structural limitations through a rigorous examination of the computer code; and
- determination of the operational characteristics of a model through experimental 'hands-on' analysis; this largely involves model simulations conducted under alternative policy and technology scenarios.

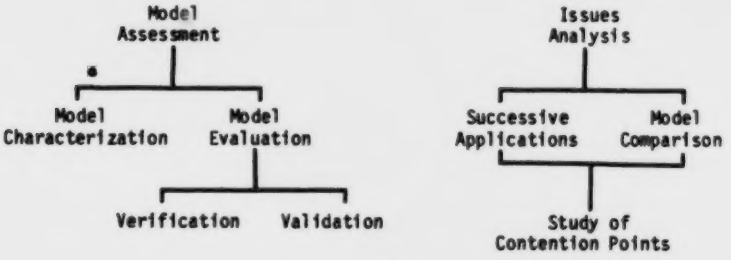
The abundance of alternative energy models has spawned a new branch of modelling which is concerned solely with critical analysis of existing models. Two major United States institutions are at the forefront in terms of this type of analysis. They are the Massachusetts Institute of Technology Model Assessment group (MIT) and the Energy Modeling Forum (EMF) located at Stanford University and sponsored by

the U.S. Electric Power Research Institute. Each group utilizes a different, though not mutually exclusive, approach to model assessment that goes beyond the descriptive model survey stage.

The MIT group typically examines a model over the full range of its capability. This procedure involves three distinct phases of investigation: a review of the literature, an overview model assessment, and an in-depth assessment. Each successive phase requires greater knowledge of the model under review. The in-depth level of assessment includes actual 'hands-on' tests to replicate the results of previous applications, conduct policy impact analysis, and experiment with test data and structural changes. This process, which we will formally refer to as 'model assessment' is designed to evaluate a model and understand it. Users are not an integral part of this operation.

The EMF approach could be termed 'issues analysis' because a number of different models are used to address a uniform set of questions (under similar sets of assumptions with respect to key exogenous variables) the results compared, and the reasons for differences among the results are discussed. User input is necessary and desirable. In fact the aim of issues analysis is to broaden user insight and understanding, not only of the models, but of the issues under examination as well. This sort of analysis then, provides a comparative commentary on the contention points of the models it employs.

The two approaches are summarized diagrammatically below with the MIT methodology represented on the left and the EMF approach on the right.



In our view, the EMF 'issues analysis' approach to model assessment is not appropriate in this case given the desire of Canadian

electrical utilities to, ultimately, have a single computerized model system to facilitate analysis for policy making and regulatory hearing activities.

With regard to the MIT approach, model characterization is essentially the task we have performed in this study. Therefore, verification of the computer code and validation of the analytical capabilities of the recommended models would be the logical next step towards meeting the Canadian Electrical Association's modelling objectives.

4.2 Cost Considerations

The other factor crucial for determining the 'best' model system from among the recommended models is the cost element. Costs associated with the next stage of the Canadian Electrical Association's modelling project can be disaggregated into six categories:

1. Acquisition: physically acquiring the model source codes, software, and databases in machine-readable form.
2. Conversion: making component models compatible with one another by implementing them on a common software and computer system.
3. Development: initial model improvement, extension and Canadianization (if appropriate).
4. Data Collection: creation of databases required for model operation.
5. Operation: computer simulation and the presentation of results.
6. Maintenance and Refinement: data updates and ongoing model development.

The first four categories are normally 'one shot' cost categories which could vary widely depending upon factors such as:

- Is the model proprietary? (Acquisition)
- How compatible are the individual models in the recommended system? (Conversion)
- Is the model Canadian? (Development)
- Is the data required for model input readily available in a compatible form? (Data Collection)

The latter two categories are the 'running' costs of a model system. They have to be incurred if a system is being used.

Operating costs also vary widely depending upon the efficiency of the computer and the code. Ongoing maintenance and refinement costs can be expected to vary according to who is responsible for the task.

Prior to considering each of these cost categories, we must point out that the 'acquisition' and 'operation' aspects are the only two to which we could attach dollar estimates with much confidence. Each of the other cost elements are dependent on a large number of factors which are either unknown or extremely difficult to accurately measure in advance. Even some of the acquisition costs estimates are 'rough' because the purchase price of consulting firms' models would depend on yet-to-be negotiated terms. For these reasons and others (which will be made apparent in the following discussion) the cost figures which we attached to the recommended models are somewhat imprecise.

4.2.1 Acquisition or Access Cost

Certain models are physically available for the cost of reproducing the model source code and data files. Examples are TESOM, REM, and the B.C. Hydro model. In these cases, ongoing data collection and model maintenance costs would not be assumed by the original developer.

In other instances, model refinement and data updates are part and parcel of accessing the model system (e.g., the Interfuel Substitution Demand Model and, probably, the DataMetrics Demand System).

In yet other situations, the acquisition cost may not be a one-time-only expenditure, but rather a per annum fee which provides access to the most up-to-date computer files. Some of the models surveyed are marketed in this manner. For example, Informetrica markets TIM through its National Forecast Service at the price of $20,000 per annum for 'hands on' users. Access to all model files and databases, biannual forecasts and workshops, and training and consulting services are provided. Similar access to the GEMS methodology would also require a sizable initial capital expenditure.

In summary then, insofar as acquisition costs are concerned, the following rough ranking can be attached to our primary recommendations (from the least to the relatively more costly models).

1. IFSDM
2. TESOM
3. DataMetrics
4. TIM
5. GEMS

4.2.2 Conversion

Associated with virtually every model that we have evaluated is a unique software package. This is a programme or a set of programmes which are required to solve the system of equations in the model. In addition, the software often facilitates one or more of the following activities: building and maintaining the model; building and updating the model database; documenting the model; and reporting results

Many different 'types' of software exist. For instance, the software may be designed and built in conjunction with the model such that the software is usable only with that model. Other systems are more general and can handle many different model structures. Some software for modelling is run in an 'interactive' mode. With an interactive system the user issues individual commands to a computer through a terminal and obtains a response. This provides a great deal of flexibility to the model user. However, interactive systems, while usually saving time for the modeller, are quite costly in terms of computer resources. Other software packages use 'batch' mode in which a user prepares a sequence of commands for the computer in an auxiliary file. These are subsequently submitted and executed independently of the user. Batch systems permit less flexibility but are comparatively less costly. So, in summary, the interactive mode may prove less expensive in terms of computer and human resources for the development, maintenance and data collection aspects of the project. However, model system size considerations alone may dictate that a batch system is preferable for the model solution phase. The most sophisticated systems allow the user to operate in either interactive or batch modes.

As we envisage it, the Canadian Electrical Association's energy modelling system could comprise a number of energy models physically linked together and using a common software system. Converting a variety of models to a common software package would have the distinct advantage of allowing the models to be operated within a single simultaneous system with full interaction among the components. Furthermore, expertise in software management would be more easily and quickly attained. The key would be to obtain a software system which can handle all of the chosen models.

When the Canadian Electrical Association's energy model system is completely specified, flexibility in the programme for solving the system of equations would be of paramount importance. The software should be capable of solving linear programming models, engineering process models and non-linear econometric models. A feature to

modularize the model system would be most useful so that any one subset of the system could be simulated independently. To report the results of forecasts and impact scenarios, programmes would be necessary to facilitate the display and analysis of results. A tabular report generator and a graphics capability would be recommended features.

A final general observation which can have significant cost implications is that the software itself should be well documented. If a commercial software package is used, a consultant should be available to respond quickly to user difficulties. We cannot overemphasize the importance of a good software package to the ease of operation and the long-run costs of operating a model system.

4.2.3 Development

Detailed assessment would reveal model 'compatibility' which has a significant impact on development costs. Undoubtedly the selected demand, supply and macroeconomic models will not mesh perfectly and development work would be required to, for example, redefine specific variables or disaggregate some sectors. This would also entail some expansion or contraction of the associated databases. If a model needs to be Canadianized or regionalized, considerable work would be required to collect the relevant data and estimate the model parameters. This might entail modification of the theoretical model if the Canadian and U.S. experiences were divergent.

4.2.4 Data Collection

Data collection costs vary widely between models. At one end of the spectrum is the Interfuel Substitution Demand Model of Energy, Mines and Resources Canada. Because data for that model are continually collected, stored and updated by the federal government, and are readily obtainable in machine-readable form this cost component would be relatively low. This also applies to the DataMetrics Energy Demand System. On the other hand, large United States models such as TESOM or GEMS would have relatively high data collection costs due to their size and the required Canadian data search.

4.2.5 Operation

Operating costs are a function of model system size, the degree of simultaneity of the system, the solution algorithm, and the type of computer and software utilized. If an iterative procedure is used to solve the model, and the greater the number of equations in the model, the more each simulation will cost. On the other hand, an iterative

methodology utilized for sensitivity analysis (as opposed to initially converging the model from a 'cold start') may be relatively inexpensive.

Given this array of considerations, it is extremely difficult to confidently rank the recommended models. For instance, GEMS requires approximately 150 seconds CPU time per iteration, and the total solution utilizes 1.5 megabytes of memory on a VAX 11-780 VMF computer. The number of iterations necessary for convergence may vary between 15-20 from a warm start, to 60-80 from a cold start. At a rate of $3 per CPU minute, then, the total execution costs (which exclude printing charges) would be in the order of $150 to $200 to converge a sensitivity-type run. Similar operation costs could be expected for TESOM.

The DataMetrics Energy Demand System for a 10 year time horizon, 7 regions and 3 sectors can be solved for approximately $50 (including report writing) through the I.P. Sharp Associates computer service (who utilize an IBM 370). This figure is similar in magnitude for the IFSDM, which operates on the EMR dual main frame computer system (CDC Twin Cyber 74's). This latter model requires approximately 17K core memory (where one K is 1000 bytes) and 250 CPU seconds to generate a solution file of 3400 PRU's in size.

TIM requires approximately 1 megabyte of memory for execution, and the total cost (execution and basic report generating) is about $100.

In summary then, with respect to solely the operation costs of the recommended models, three groups present themselves: the least costly (DataMetrics and the IFSDM), the more costly (TIM), and the most costly (GEMS and TESOM). It should be cautioned though that comparing models with distinctly different design purposes in such a manner is somewhat deceiving. We would also note that solving a combined system of models (energy supply, demand, and macroeconomic) will likely cost more than the sum of costs for the individual models.

4.2.6 Maintenance and Refinement

The data maintenance cost will vary depending upon the requirements of the individual models and whether or not an original model developer updates the data base as in the case of the Energy, Mines and Resources demand model.

Ongoing model refinement will serve to strengthen those portions of the modelling system that were of relatively less

importance in the initial model development phase. The costs involved will reflect the priority to which the sponsor attaches to these imperfections.

In order to be more precise in our recommendations, then, these are the types of costs that should be subject to a period of intensive investigation with all relevant parties involved. Even the most theoretically sound models must be viewed in the practical context of implementation cost.

APPENDICES

APPENDIX A
LIST OF PERSONAL CONTACTS

Joseph Ashbury
Argonne National Laboratory

Martin Baughman
Centre for Energy Studies
University of Texas, at Austin

Peter Brakel
Dept. of Industry, Trade & Commerce
Government of Canada

Ed Cazelet
Decision Focus Inc.

Tom Cowing
New York State University

Victor De Buen
Generation Planning Department
B.C. Hydro and Power Authority

Terry Daniel
Faculty of Business Administration & Commerce
Administration University of Alberta

David Dent
Ontario Hydro

Al Evans
Argonne National Laboratory

M. Francony
Electricite de France

Dave Fuller
Faculty of Commerce
University of British Columbia

Saul Gass
Faculty of Business Management
University of Maryland

Steve George
Charles River Associates

Tim Glidden
Dartmouth College

Cliff Halliwell
Conference Board in Canada

M. Hamza
Department of Electrical Engineering
University of Calgary

John Hanson
Charles River Associates

John Helliwell
Department of Economics
University of British Columbia

Ken Hoffman
Math Tech Inc.

Rick Huff
Data Resources Inc.

Alex Karas
National Energy Board

Andy Kydes
Energy Information Administration
U.S. Department of Energy

Bill Jarvis
Informetrica

Lester Lave
Carnegie-Mellon University

Charles Macal
Energy & Environmental Systems Division
Div Argonne National Laboratory

Alan Manne
Stanford University

Bill Martin
International Energy Agency

Robert McRae
Department of Economics
University of Calgary

John Melvin
Atomic Energy Company of Canada Ltd.

Phiroze Nagarvala
Research & Energy
Bechtel Corporation

Vic Niemeyer
Electric Power Research Institute

Jim Osten
Data Resources Inc.

B. Pearson
SNC Group

Stephen Peck
Electric Power Research Institute

Don Quon
University of Alberta and
Alberta Research Council

Joseph Rabinowitz
Brookhaven National Laboratory

Scott Rodgers
Department of Electrical Engineering
University of Toronto

H. Rogner
International Institute for Applied Systems Analysis

John Rowse
Department of Economics
University of Calgary

Carlos Samur
National Energy Board

V. Sassin
International Institute for Applied Systems Analysis

Carl Sather
Argonne National Laboratory

Kurt Schenk
National Energy Board

Fred Schweppe
Massachusetts Institute of Technology

C. Hoff Stauffer, Jr.
ICF, Incorporated

John Trimble
Oakridge National Laboratory

William Shelson
Energy Resources Planning
Ontario Hydro

Robert Shotton
European Economic Commission

G. Campbell Watkins
DataMetrics Limited

Len Waverman
University of Toronto

John Weyant
Energy Modeling Forum
Stanford Universty

Dave Whillans
Energy, Mines & Resources

Tom Wilson
Stanford University

William Ziemba
University of British
Columbia

APPENDIX B
BASIC STRUCTURAL METHODOLOGIES

The architecture of large scale energy models varies widely. The purpose of this appendix is to discuss the correspondence between economic theory and specific modelling methodologies. Two general examples will be investigated and related to a single theoretical concept: that of general economic equilibrium.[1]

A model of general economic equilibrium is in essence a model of a production/exchange economy in a state of supply/demand balance. The model provides a set of technological and behavioural assumptions under which there will exist:

- an equilibrium price vector;
- a set of equilibrium production levels; and
- a set of equilibrium consumption levels.

In the discussion below, we stop short of addressing questions concerning the existence, uniqueness, stability, and solvability of the equations characterizing general economic equilibrium.[2] We are more interested in the manner in which equilibrium conditions are made operational in energy models.

B.1 Equilibrium in a Spatial Network[3]

Basic Theory

Figure B.1 illustrates a simple spatial network, where the circle represents an activity where a commodity is being demanded, and the square designates a point where a commodity is produced by a given technology.

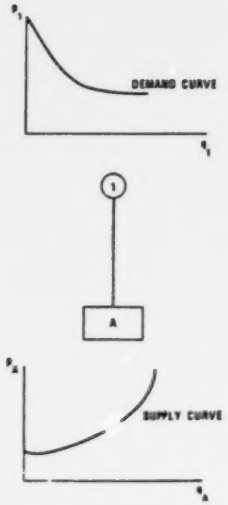


Figure B.1: Simple Network Methodology

One could imagine the following successive extensions to this basic diagram:

- assume more than one end user, in which case more than one demand curve would interact with a single supply curve.

  In a perfectly competitive market the profit motive would encourage the supplier to reallocate supplies until all end users paid the same price. Thus an aggregate demand curve could be formed by the horizontal sum of each of the two (or more) individual end user demand curves. So the solution of the network reduces to the simple case of Figure B.1

- assume multiple suppliers of the same good, or in energy terms, introduce interfuel competition

  End users will attempt to reduce their cost by switching to alternative sources of supply until there is no further incentive to change. That equilibrium condition implies that the supply curves too can be added horizontally to obtain an aggregate supply curve.

Now a more complex extension. Assume that between the suppliers and end users some conversion, transportation and distribution processes are incorporated.

Figure B.2 denotes this situation, using for an example the natural gas market.

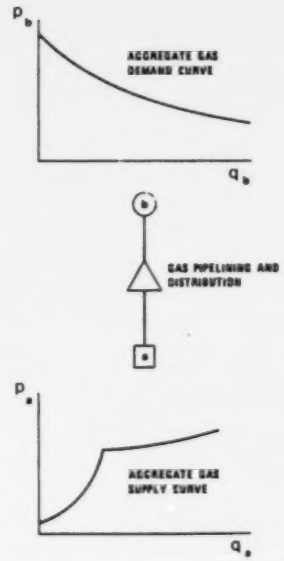


Figure B.2: Illustrative Gas Network

Further, define,

e = thermal efficiency of the gas pipeline and distribution process (the Btu's of delivered gas per Btu of gas at the source); and

c = operating and maintenance cost plus capital charge per Btu of delivered gas, including nominal return on investment (c is assumed to be exogenously given).

Assuming that the price and quantity of gas at the source are p_a per Btu and q_a Btu respectively, the price of delivered gas p_b will satisfy the relation

$$p_b = \frac{p_a}{e} + c \tag{1}$$

and the quantity of delivered gas q_b satisfies the relation

$$q_b = e_a \tag{2}$$

We now consider how the supply curve at 'a' is transformed as it passes through the pipeline to 'b'. All prices are transformed (increased) according to equation (1) and quantities are transformed (decreased) according to (2).

A similar transformation can be performed on the demand curve. Equation (1) can be rearranged to give

$$p_a = e(p_b - c) \tag{3}$$

and equation (2) can be rearranged to give

$$q_a = \frac{q_b}{e} \tag{4}$$

Therefore, the equilibrium condition for the network in Figure B.2 consists of two supply-demand equilibria holding jointly--one at 'a' and one at 'b'.

Extension to Large-Scale Networks

Refer to Figure B.3 for an example of a large-scale network. The basic resource supply curves of the energy network appear at the bottom of this figure. The demand curves for end use energy appear at the top of the network. These two sets of curves define the 'boundary' of the network.

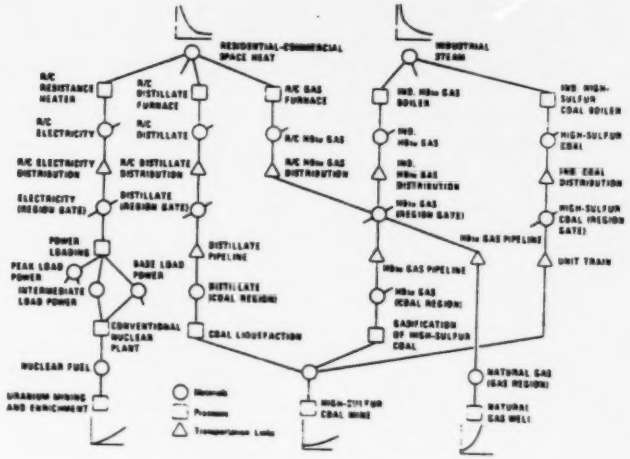


Figure B.3: Elements of an Energy Network

In view of the previous discussion of the basic theory involved, three statements can be made regarding general equilibrium in such a large- scale network:

- there exists an aggregate demand curve and an aggregate supply curve at every material node (circle) in the network;
- there exists a supply curve and a demand curve on every link in the network. Any such pair characterizes the supply/demand conditions governing the behaviour of the (unique) conversion or transportation process attached to the link.
- the equilibrium prices and quantities are those for which all aggregate supply/demand curve pairs are simultaneously balanced at all material nodes; or equivalently, for which all supply/demand curve pairs are balanced on all the links of the network.

B.2 Equilibrium in a Translog and Variable Coefficient Input-Output Framework[4]

To demonstrate how the components of this methodology interact to form a general equilibrium model, theory will first be developed for the production and consumption sectors, and then the input-output concept will be introduced.

Translog Theory of Production and Consumption

Let:

$\underline{w} = (w_1,\ldots,w_n)$ denote the vector of input prices,

$\underline{x} = (x_1,\ldots,x_m)$ denote the vector of output quantities, and

$\underline{e} = (\ln w_1,\ldots,\ln w_n;\ \ln x_1,\ldots,\ln x_m)^T$ denote the vector of the natural logarithms of input prices and output quantities in column vector form.

Then the logarithm of the cost possibility frontier, $\ln V(\underline{w},\underline{x})$, can be written as a function which is quadratic in the logarithms of input prices and output quantities:

$$\ln V(\underline{w},\underline{x}) = a + \underline{e}^T\underline{b} + 1/2\underline{e}^T Q\underline{e} \tag{5}$$

where a is a scalar, $\underline{b}$ is an $(n+m)$-vector, and Q is an $(n+m)$ x $(n+m)$ matrix. This is a second order Taylor series expansion in the logs of $\underline{w}$ and $\underline{x}$.

By differentiating (5), making various substitutions and utilizing the definition of a logarithm, two functional forms can be obtained that can be estimated econometrically.

$$\frac{w_i z_i^*}{\sum_{k=1}^{n} w_k z_k^*} = b_i + Q_i\underline{e} \qquad i=1,\ldots,n \tag{6}$$

and

$$\frac{p_{j-n} x_{j-n}^*}{\sum_{k=1}^{n} w_k z_k^*} = b_j + Q_j\underline{e} \qquad j=n+1,\ldots,n+m$$

where the $*$ represents optimum points.

Equations (6) and (7) are linear in the coefficients $b_1,\ldots,b_{n+m}$, and $Q_1,\ldots,Q_{n+m}$. Furthermore, they contain 'real world observables'. In the case of (6), the left-hand side represents the dollar shares of total cost accounted for by the i^{th} input. In (7), the left-hand side denotes the dollar shares of the total value of the firms' output accounted for by the j^{th} output. On the right-hand side of both (6) and (7), the vector $\underline{e}$ contains logarithms of input prices w_k and output quantities x_j. Econometric techniques can then be utilized to estimate the coefficients b and Q.

The analytical problems involved in developing utility functions for the consumption side are strictly analogous to those concerned with production.

Define a vector $\underline{d} = (\ln y_1,\ldots,\ln y_n, \ln \ell)^T$ where y_i denotes the level of final demand for good i and denotes the level of leisure time. The logarithm of the utility function can be written as a Taylor expansion to second order:

$$\ln u(\underline{y},\ell) = t + \underline{d}^T\underline{s} + 1/2\underline{d}^T R\underline{d} \tag{8}$$

where t is a constant, $\underline{s}$ is an $(n+1)$-vector and R is an $(n+1)x(n+1)$ matrix.

By making a series of substitutions similar to those made in the above analysis of the translog cost frontier we can obtain a functional form amenable to empirical estimation:

$$s_i + r_i\,\underline{d} = \frac{p_i y_i^*}{w\ell} \sum_{j=1}^{n} s_j + \underline{r}_j\,\underline{d} \qquad i=1,\ldots,n \tag{9}$$

and

$$s_{n+1} + \underline{r}_{n+1}\,\underline{d} = \frac{w\ell}{wL} \sum_{j=1}^{n} s_j + \underline{r}_j\underline{d} \qquad j=n+1,\ldots,n+m \tag{10}$$

The terms on the left-hand sides of (9) and (10) are 'observables' in the real world (representing the 'dollar share' of total consumer purchases accounted for by the i^{th} commodity). Likewise, the elements of $\underline{d}$, the logarithms of the commodities consumed and of the level of leisure (labour), are measurable. Using these equations then, econometric techniques can be used directly to estimate $\underline{s}$ and $\underline{r}$, given observations of the other terms.

Interpretation of Input-Output Equilibrium

A simple two industry characterization of the preceeding theory could be represented diagramatically as follows:

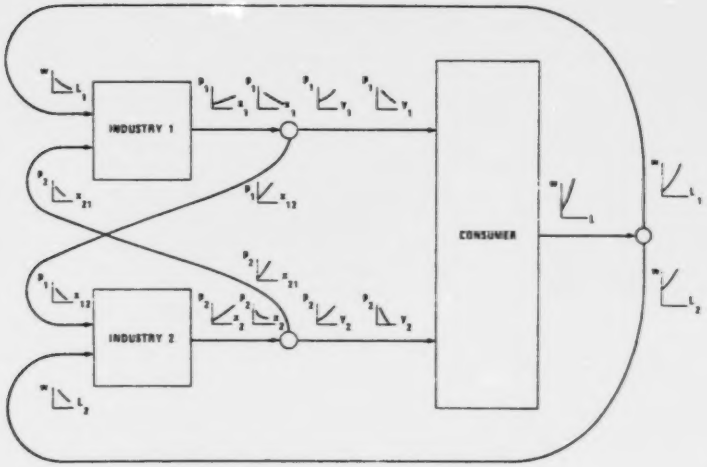


Figure B.4: Supply-Demand Curve Representation

Two sets of input-output equations must hold in the industrial sector at equilibrium, one set in terms of quantity flows and the other in terms of dollar flows. These equations follow.

$$\frac{w_i z_i^*}{p_j x_j^*} \triangleq b_{ij} \tag{11}$$

The input-output coefficient b_{ij} represents the dollars worth of the i^{th} input required to produce one dollar's worth of the j^{th} output. The input-output coefficient b_{ij} should be regarded as functions of all input and output prices and quantities of all technologies. The physical flow input-output coefficient from the i^{th} input to the j^{th} output is defined as:

$$\frac{z_i^*}{x_j^*} \triangleq a_{ij} \tag{12}$$

The two input-output coefficients a_{ij} and b_{ij} are related in a straightforward manner:

$$b_{ij} = \frac{w_i}{p_j} a_{ij}$$

Using these definitions of the input-output coefficients and balancing dollar flows at circles 1 and 2 in Figure B.4, the following equations can be obtained:

$$(p_1x_1^*) - b_{12}(p_2x_2^*) = p_1y_1$$

$$-b_{21}(p_1x_1^*) + (p_2x_2^*) = p_2y_2$$

which must hold at equilibrium. These equations can be written in matrix form as follows:

$$\left\{ I - \begin{bmatrix} 0 & b_{12} \\ b_{21} & 0 \end{bmatrix} \right\} \begin{bmatrix} p_1x_1^* \\ p_2x_2^* \end{bmatrix} = \begin{bmatrix} p_1y_1^* \\ p_2y_2^* \end{bmatrix}$$

By defining the input-output matrix (where neither industry requires its own output as an input) as,

$$B = \begin{bmatrix} 0 & b_{12} \\ b_{21} & 0 \end{bmatrix}$$

then an input-output equation describing dollar flows at equilibrium can be written;

$$\left[I-B\right]^{-1} (\underline{py}^*) = (\underline{px}^*) \tag{13}$$

where the i^{th} element of $\underline{py}^*$ is $p_iy_i^*$, and similarly for $\underline{px}^*$.

Proceeding through a similar development for the material flows, the input-output equation describing material flows at equilibrium is

$$\left[I-A\right]^{-1} \underline{y}^* = \underline{x}^* \quad . \tag{14}$$

When the equilibrium values of $\underline{w}$, $\underline{p}$, and $\underline{x}^*$ are independent of the configuration of final demands $\underline{y}^*$, the above input-output equations can be used to 'solve' for equilibrium prices and quantities.

Footnotes

[1]Much of what follows is a compendium of several sources; for instance, Charles River Associates (EPRI EA-968) and Brock and Nesbitt, 1977.

[2]Any advanced micro text will look at these theoretical considerations; for example, see Quirk and Saposnik, Introduction to General Equilibrium Theory and Welfare Economics, (McGraw-Hill: New York), 1968.

[3]To keep this appendix in manageable proportions, this section has been generalized to describe the network theory represented in two major energy models; the SRI-Gulf and the BESOM models. Insofar as structural description goes such an aggregation seems legitimate; although the two models utilize distinctly different methods for the actual computation of equilibrium.

[4]This type of a methodology is similar to that represented in the Hudson-Jorgenson modelling approach.

APPENDIX C
BASIC SOLUTION TECHNIQUES

The following discussion briefly describes some of the traditional modelling techniques which are employed in model building. These techniques are the basis for the models reviewed; however, some models employ combinations or variations of these techniques.

C.1 Mathematical Programming

Programming models deal explicitly with the problem of allocating limited resources among competing activities in an optimal manner. Decision makers are characterized as having perfect foresight; all past, present and future values of variables are assumed known.

Mathematical programming differs from classical optimization (calculus) in that it seeks to tackle problems in which the decision-maker faces inequality constraints--constraints in the form of $g(x,y) \leq c$ rather than $g(x,y) = c$. By liberalizing the constraint requirement, this particular framework of optimization offers a much larger flexibility.

Mathematical programming has successfully been used in energy system modelling to capture the technical or engineering details of specific energy supply and utilization processes in a framework amenable to economic interpretation. In such models, arrays of variables are defined representing the levels of activity in specific processes. These are arranged in a series of simultaneous equations representing, for example, demand requirements, supply constraints, and any other special relationships that must be defined to typify economic or physical reality.

Because of its clairvoyant nature, this technique provides an optimistic bound of what the system can potentially achieve given that the 'right' decisions are made in each time period. This method then, is most often utilized for planning purposes rather than for forecasting (i.e., what should be done, as opposed to what will actually occur).

Linear programming, the most widely utilized branch of mathematical programming, is a technique traditionally used to find the

optimum solution to the classical transportation problem--using inputs from various sources to produce a given output.

The most basic LP energy problem definition often takes the following form.

Minimize:

$$\sum_i \sum_j c_{ij} \quad x_{ij} \qquad \text{where } i \text{ is the supply area index and } j \text{ is the demand area index} \qquad (1)$$

Subject to:

$$\sum_j x_{ij} \leq S_i \qquad \text{for each } i \qquad \text{supply constraints}$$

$$\sum_i x_{ij} = D_j \qquad \text{for each } j \qquad \text{demand constraints}$$

$$x_{ij} \geq 0 \qquad \text{for all } i,j$$

Variables x_{ij} represent the flow of resources from supply area i to demand center j. Price coefficients, c_{ij} typically include supply, transportation, and cost and revenue components. S_i are supply limits and D_j are resource demands.

In short, then, there are three essential ingredients in a linear program: an objective function, a set of constraints, and a set of nonnegativity restrictions.

A linear program can be used to find the optimum mix of resources combined with various processes and transportation links to supply required energy. The linear program also can be used to calculate the energy prices and flows at each point in the system defined by the various processes and transportation links.

Linear programming is a powerful mathematical tool. It allows a large amount of information to be incorporated into a formalized framework. This ability to incorporate large amounts of data is also probably the largest drawback to linear programming. Costs and efficiencies of each link in the system must be provided. Other parameters, such as emissions, also must be provided if they are to be included in the optimization. Compiling this large amount of information

is tedious and time consuming. Another limitation of linear programming is the necessity of formulating the model stricly in linear relationships. Non-linear relationships can be handled but require a step-wise solution where each step represents a linear formulation.

C.2 Econometrics

Econometric analysis characterizes decision makers as unable to incorporate future variables in present decision making. This approach is often used in economic models to gain simplicity or because of data limitations.

For instance, the demand for energy originates from so many sources that it is not practical to apply a process-type analysis descriptive of individual activities. Such a simple econometric model could be expressed as follows:

$$Y_j = a + bX_j \qquad (2)$$

where X and Y are price and quantity time-series vectors and a and b are the population parameters of the linear relation between X and Y to be estimated from observations on a sample size n. In econometric estimation the assumption of exact relationships must be discarded. Therefore a stochastic or disturbance term U is added to the linear relation since linear or other simple forms only approximate the possibly complex, but unknown, true functional form and also because only a small subset of all possible explanatory variables can usually be included in the specification. So equation (8) can be rewritten as:

$$Y_j = a + bX_j + U_j \qquad (3)$$

The parameters a and b are estimated in the simplist case by the ordinary least squares method which minimizes the sum of the squared deviations. For example

$$\hat{b} = \sum_{j=1}^{n} x_j y_j \quad \sum_{j=1}^{n} x_j^2, \qquad j = 1,2,\ldots,n;$$

where x_j and y_j are deviations from their respective means

$(x_j = X_j - \overline{X},\ y_j = Y_j - \overline{Y})$.

Therefore b is a linear 'unbiased' estimator; the theoretical mean of the sampling distribution of b is equal to the population b. This sampling distribution has the minimum variance of all linear estimators

from fixed sample X_j. It is therefore 'best' in the sense that, of all linear estimators, no other gets closer to the true b more often.

More sophisticated functional forms and estimation techniques are available.

Econometric methods are generally used in modelling behavioural and/or technological relationships. Behavioural processes are characterized by a decision-making agent hypothesized to adjust behaviour in response to changes in variables outside his direct control. Technical relationships, on the other hand, describe purely physical processes, an example of which would be a production function.

In summary then, econometric analysis provides a method of describing uncertain and aggregate behaviour wherein the effects of price changes can readily be isolated through the concept of elasticity; therefore it is well suited for economic policy impact analysis. The reliance on historical data provides for some degree of model validity, but it also limits this validity to the range of conditions represented by the data.

C.3 Engineering Process Analysis

Above all, process models are disaggregated models. They distinguish a large number of economic agents, some of them on an individual basis, and keep track of a large number of transactions among agents. As much disaggregation as possible is generally desirable, to avoid 'aggregation error' which arises when a change in a variable merely reflects a change in the weights attached to composite units rather than a change in the behaviour of specific units.

Process analysis might best be described by contrasting it to econometrics. Econometrics is a macro-technique; the emphasis is placed on describing aggregate changes by a number of individuals or businesses. Engineering process analysis, on the other hand, is a micro-technique, emphasizing the description of how a single business or industry acts and the reasoning behind its actions. This latter type of analysis normally deals with cost trade-offs or technical considerations.

When properly used in a model, this technique gives an accurate representation of how individual components of the system operate under a range of conditions. Its use requires an in-depth knowledge of how the industries or businesses modelled operate.

C.4 Network Analysis

Network analysis is similar in many respects to linear programming. A similar network of processes and transportation links is used to simulate the energy system; however, network analysis does not require linear relationships and normally uses unconstrained relationships. The specific mathematical formulation used for each relationship is largely left to the user's discretion. Network analysis is considerably different in function from linear programming. Rather than determining a system optimum, network analysis describes how each link in the network will act under given conditions.

The network anlaysis formulation allows the incorporation of much of the same information as linear programming and, thus, some of the same advantages and disadvantages. Network analysis can be combined with similar supply and demand information to determine system configuration. These calculations normally require an iterative solution. As a result of the non-linear formulation, sophisticated algorithms are usually required to guarantee convergence to a solution.

C.5 Systems Dynamics

Systems dynamics is a modeling technique which is based after the state variable representation used extensively in electrical and mechanical systems analysis. Systems dynamics originally was designed to study dynamics in industrial systems, but has since been adapted for use in studying a wide range of economic and social questions. There is no rigid form to a systems dynamics model; the particular form used in a model is developed largely by the model builder. Systems dynamics models emphasize change in the system modelled. The important model relationships centre around the forces which cause this change.

The flexibility in the format of a systems dynamics model is both the technique's greatest asset and its greatest liability. The format allows models to be developed for each application with no constraints as to how the system structure should be defined. It also places the burden of defining this structure upon the model builder, resulting in a wide range in both the sophistication and quality of systems dynamics models.

C.6 Input/Output Analysis

Input/Output (I/O) analysis is a method which relates the inputs required from various economic sectors to manufacture or

otherwise produce the ouput of each sector. A large matrix of coefficients relating these inputs and outputs is the core of any I/O analysis. Through matric manipulation, other information can be derived.

I/O analysis is commonly used to calculate the net increase in output of all sectors which results from an increase in any other sector. I/O analysis, in principle, can be applied to a region of any size though its emphasis on the interactions between sectors makes it more suitable for larger regions. Also, the normally assumed linear nature of I/O analysis limits the time period for which it is accurate.

Each of the modeling techniques described has certain areas where it is particularly suited. Linear programming and network analysis are both well suited for handling large, complex systems in a structured manner. The optimization ability of linear programming is useful in showing how the energy system should or could operate. Network analysis is useful in incorporating a large number of system processes into a simulation of the energy system. Systems dynamics is more suited for showing long-term trends in the system involving major changes. Systems dynamics may also be useful in showing transients which occur as changes take place. Econometric techniques are useful in describing aggregate energy demands. Econometric relationships are usually the link tying energy models to driving economic parameters. I/O techniques traditionally have been used more in conjunction with overall economic models rather than in energy systems analysis. They may serve this same role in energy systems models which are tied to a model of the economy. Engineering process analysis provides the detailed assessment needed for thorough descriptions in specific studies.

APPENDIX D
MODEL-SPECIFIC EVALUATIONS

The purpose of this appendix is to present in more detail the basis upon which our recommendations were made. To this end, the relevant characteristics of each model are summarized on the following pages in a consistent format.

The energy models (energy system, sector and industry models) are examined in alphabetical order according to the acronym by which they are commonly referred; the description of the eight Canadian macroeconomic frameworks are appended to the end.

The format in which models are discussed is largely self-explanatory. 'System Described' refers to the design purpose of the particular model. Specific articles referenced by author and date for brevity, under the heading 'Published Commentary', may be located in the Bibliography. It should be cautioned also that the 'Advantages' and 'Disadvantages' indicated are the authors' opinions based upon the limited amount of published documentation that we have at our disposal.

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Argonne Coal Market Model (ACM) Argonne National Laboratory	This model was used to generate long-term coal market scenarios that became the basis for comparing the impacts of coal development options. Coal demands are forecast by a combination of trend and econometric analysis and then input exogenously into the model. Coal supply in each region is characterized by a linearly increasing function relating increments of new mine capacity to the marginal cost of extraction. Rail transportation costs are econometrically estimated for each supply-demand link. A quadratic programming algorithm is used to calculate flow patterns that minimize consumer costs for the system.	Description 1. Dux, Krohm and VanKuiken, 1977. Application 2. EPRI EA-967, 1979.	• regionally disaggregated to make transportation charges more accurate, and to differentiate among coals of different quality characteristics • explicitly designed to handle the implications of a wide range of environmental policies • flexible and low cost solution algorithm	• coal demands are estimated outside of the main model; no feedback mechanism exists then, between price and future levels of demand, nor coal price and other fuel types • the long-run market supply functions utilized are based upon work done by ICF, Inc.; whether the methodology is consistent across these models is not clear

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Alberta Energy Resources Allocation Model (AERAM) D. McConaghy D. Quon Alberta Research Council	Designed to address general policy issues pertinent to Alberta hydrocarbon resource base. The model describes the future optimal allocation of the hydrocarbon resource base required to satisfy both provincial and national primary energy demands under various scenarios. More precisely, it is a comprehensive intertemporal supply allocation model. The energy system modelled is considered as a supply-demand network linking primary energy resources to final demand energy products. Intermediate nodes represent the relevant energy extraction or conversion processes.	Description 1. McConaghy and Quon, in Ziemba and Schwartz, 1980. 2. Quon, technical description, draft report, 1980. 3. EMR/ARC Modelling Conference, 1978. Application 4. Quon, McConaghy and Wong, 1980.	• the model is not a forecasting tool, rather a demand scenario would be input and a least cost energy development strategy would result; this aspect would make AERAM an attractive supplement to a larger system, though not the mainstay • great detail is provided at the refinery level • a detailed and endogenous coal supply representation	• lacks a well developed electricity sector • concentrates on Alberta only • relatively short-term horizon of 15 years
The Canadian BALANCE Model T. Daniel M. Goldberg Imperial Oil Ltd. J.D. Muir Research	The model is a multi-time-period linear programming formulation of Canadian energy supply integrated with the EMR Inter-Fuel Substitution Demand Model). The model finds an equilibrium set of prices, supplies and demands over all time periods using a new dynamic version of the equilibrium-seeking algorithm developed for the Project Independence Evaluation System.	Description 1. Ziemba and Schwartz, 1980. 2. Daniel and Goldberg, 1980.	• though simplistic, the handling of primary energy supply provides clarity and ease of analysis • one of the few integrated energy models in Canada	• time periods are five year intervals • the oil and gas conversion process representation is not as detailed as AERAM • the EMR demand model is not physically linked with the supply side but rather operated independently, thus no explicit feedback mechanisms exists between the two • primary resource supply functions are first-order estimates

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
British Columbia Energy System Model V. de Buen British Columbia Hydro and Power Authority	A linear programming model of the British Columbia energy system designed to establish the optimum utilization of alternative energy forms available to the province. The model minimizes the total costs involved in the production, conversion, transportation, distribution and utilization of the different resources available for energy in the residential, commercial, industrial and transportation sectors.	Description - V. de Buen, 1979 Application - strictly within B.C.	• emphasis on electric power system and used as an input to the utility's system planning process • detail in electricity transmission and distribution and in natural gas system • cost of extending application to certain other provinces would be relatively low • have used integer programming to improve precision in the simulation of electricity generation	• supply curves are required to improve upon primary resource representation

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Brookhaven Energy System Optimizing Model (BESOM)	BESOM is a detailed static linear programming model that was developed for long-range technology assessment and policy analysis. The model is designed to examine interfuel substitutions in the context of constraints on the availability of competing resources and technologies. BESOM is structured around a Reference Energy System that depicts the flow of energy from a resource to all points of actual end-use.	Description 1. Kydes Tn Ziemba and Schwartz, 1980. 2. EPRI EA-968, 1978. 3. Behling, 1976. Application 4. BESOM used with H-J model by ERDA, 1976. Review 5. EPRI EA-837, 1978. 6. Manne, et al, 1978. 7. Brock and Nesbitt, 1977. 8. Hoffman and Wood, 1976.	• can be used in an optimization mode or a simulation mode • has an environmental impact component • explicit treatment of energy supply, conversion, transportation, distribution and utilization technologies • has been linked with economy models such as Illinois Input-Output and Hudson-Jorgensen Long Term Industry Transactions Model	• expensive to operate and maintain • strictly a linear objective function • no elasticities and as such interfuel substitution based only on engineering process analysis • optimization is performed on basis of annual cost in a single budget year rather than mix present worth over some planning horizon--typically results generated for only 1985 and 2000 • no explicit treatment of plant expansion, exhaustible resources or capital • activity analysis models (such as BESOM and DESOM) require extreme disaggregation to avoid a tendency for the supply source with the lowest average cost/unit to dominate a major end-use category

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
BALLOG William Hardhaus Massachussetts Institute of Technology	BALLOG is an economic model of energy demand integrated with a dynamic activity analysis model of energy supply. Designed for long-term analysis of energy resource allocation options, BALLOG has been extensively used in long-range assessment of nuclear and alternative technologies.	Description 1. Hoffman and Wood, 1976. 2. Groenberger and Nichols, 1979. Application and Review 3. Congas, 1978. 4. EPRI EA-968, 1979. 5. Hughes, 1979.	• more detailed than ETA-MACRO on demand side • relatively compact structure allows for ease of operation	• like other sectorwide activity analysis models it optimizes on basis of average cost/Btu for large supply and end-use categories • quality differences among energy forms and differences in cost/Btu between different fuels is ignored; therefore can produce accurate results only through imposing constraints • there is no interfuel substitution on the demand side • more restrictive supply side than DESOM or ETA-Macro

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Coal and Electric Utilities Model (CEUM) ICF, Incorporated United States, Department of Energy Electric Power Research Institute	Designed to examine supply, demand and price conditions in the coal industry as a whole. A supply component, via a transportation network, provides coal to satisfy the demand from both utility and non-utility consumers at least cost. In so doing, coal production, consumption and price are established and reported by region (30 supply regions, 39 demand regions), consuming sector (6) and coal-type (36 varieties). This is a refined and extended version of ICF's National Coal Model, a critique of which is given in Gordon, 1979.	Description 1. ICF, Incorporated, 1980. Review 2. Goldman and Gruhl, in Gass, 1980.	• the scope of analysis is sufficiently broad to incorporate electricity sector specifics; for instance, the optimal way to generate exogenously specified levels of electricity demand is determined given factor costs and the prevailing environmental regulations • utility system expansion planning and inter-regional transmission is also explicity modelled • a high level of disaggregation; for instance, there are about 200 supply curves in the model, each representing a specific coal-type in one of the 30 supply regions • environmental standards for electricity generation are considered in detail	• coal demands for non-utility sectors are given outside the model, some of which are insensitive to price fluctuations • due to the high level of activity disaggregation, for computational feasibility, it was necessary to employ a simple LP solution methodology; the underlying assumptions then, are fixed proportion production processes and pure competition

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Coal Market Analysis System (CMAS) Charles River Associates Electric Power Research Institute	Designed as a regionally disaggregated model of the coal industry as a whole. This system uses a mathematical programming model to solve for market clearing prices and production of a spatially articulated market, in which users choose the lowest cost fuel source and competition among producers is sufficient to prohibit excess profits. This is an extended and updated version of a national coal model developed by CRA for the Potomac Electric Power Company. CMAS will in turn be superceded by the "EPRI Coal Supply Analysis System" when it becomes available; only a design description is currently available for the latter model.	Description 1. EPRI EA-1086, 1979. 2. EPRI EA-907, Vols. 1-4, 1979. 3. Dunbar and Mahring, 1977. Application 4. Stanford University, 1979. Review 5. Gordon, 1977.	• explicitly allows for cost variations among mines at a particular time and for the occurrence of depletion effects over time • a dual horizon approach is taken to forecasting supply responses to price changes due to the time required to open new mines; for the first three years output is not responsive to changes in demand, whereas, beyond the fourth year, coal supply can adjust to demand • this model is operational on a commercial computer accessible through a national network	• utility coal demand is exogenously input and is then allocated to demand regions using information on locations of generating stations and their emission regulations; thus no explicit feedback mechanism exists between price and demand

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Canadian Welfare Equilibrium Model (CWEM) D. Quon Alberta Research Council Energy and Natural Resources University of Alberta	CWEM is a large scale, inter-temporal, market equilibrium, energy-economy policy model), patterned after the PILOT project at Stanford University The clairvoyant and optimizing features provide a solution depicting the upper bound of achievement assuming the 'right' allocative decisions are made.	Description 1. Quon, undated.	• energy-economy interaction is explicit • supply cost functions for all primary resources are presented • it is presently being 'Canadianized' insofar as structure and data inputs are concerned • with respect to its macro component it utilizes a neoclassical growth model as opposed to a demand driven model; which offers advantages in long term simulation • the I-O configuration that it utilizes features variable coefficients; a unique feature with respect to Canadian macro-models	• it is national in scope; thus indicating too high a level of aggregation on the energy supply side • will initially have only two non-energy sectors in the economy • not yet operational

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Dartmouth College Energy Model	The Dartmouth College model is a 'system dynamics' simulation of the electricity, coal and oil and gas industries in the U.S. The purpose of the model is to study the behaviour of the rate of production, price and investment policy in the electricity industry	Description and Application 1. EPRI EA-696, 1977. 2. EPRI EA-967, 1979. 3. EMF 5.4, 1978. Survey 4. Brock and Nesbitt, 1977.	• emphasis on the electricity industry • good price-quantity and capacity feedback relationships	• consideration of the economy outside of the energy industries is limited to an exogenously specified demand for energy by the non-energy producing sectors • generally highly aggregated both geographically and technologically • model equations depend heavily on user judgment rather than empirical evidence or economic theory • the large lag times insure a sluggish adjustment process • generally has received poor reviews in other model surveys

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
DataMet·ics Energy Demand system G. C. Watkins E. Berndt Nova, An Alberta Corporation	The DataMetrics system is a Canadian total energy demand model for each sector and region which is similar in basic structure to the EMR demand models in that it utilizes a 'top down' approach. The system models three demand sectors in each of seven regions. A total energy demand equation is first estimated for each consuming sector and each region. The product of total energy demand and the fuel share defines the demand for an individual fuel type.	Description and Application 1. DataMetrics, 1980. 2. Watkins, 1980.	· dynamic adjustment capability is a significant advantage · very good data base which goes beyond published sources · Datametrics has the capability to significantly disaggregate the industrial sector based on prior experience · trans-log estimation approach as in Hudson-Jorgenson model provides a flexible functional form	· most recent modelling activity has ignored transportation uses of fuels and fuels used to generate electricity · the model system is in a relatively early stage of development and application; model specification and data employed are still being improved · programmed in APL; this language is not as efficient for simulation as many other languages nor would it be as easy to integrate with other models
Dynamic Energy System Optimization Model (DESOM) E. Chernlasky W. Marcuse U.S. Energy Research and Development Administration Electric Power Research Institute	Dynamic version of basic BESOM structure. DESOM identifies capital outlays separately from operating costs and optimize on a present worth basis. DESOM may be thought of as a sequence of BESOM's, each with constraints, linked together by capacity transfer and resource availability constraints.	Description and Application 1. EPRI EA-1079, 1979 Review 2. EPRI EA-968, 1978 3. Conaes, 1978 4. Hitch, 1977 5. Brock and Nesbitt, 1977	· unlike BESOM treats plant expansion, exhaustible resources and capital requirement explicitly · explicit representation of load duration curves in the electricity sector	· no own-price sensitivity with respect to energy demand · as with BESOM linearity of objective function is an oversimplification

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Canadian Energy Demand Model (DRI) J. Oxton Data Resources Incorporated	The proposed Canadian Energy Demand model is a regional, full energy system model forecasting prices and demands for all major energy forms.	Description 1. Data Resources of Canada, 1979. Application -Unknown	• highly disaggregated in all areas • expertise on U.S. energy scene available in parent company of DRI • potential of integration with DRI macro model are very good	• regional model is currently and unknown entity; still in development stage • no indication regarding current ability of model to meet capabilities stated in Canadian Energy Service proposal
Elephant-Rabbit Model W. Hogan A. Manne	E-R is a very simple model of energy-economy interactions. All of the economy's inputs are aggregated into two categories--energy (rabbit) and everything else (elephant). The 'moral' this simple exercise is meant to convey is that the energy component is fairly insignificant when compared to the aggregate economy.	Description 1. MITEM, 1977. 2. Ziemba and Schwartz, 1980. Application 3. Hogan and Manne, 1977.	• gives an overview of energy-GNP interdependence and organizes central concepts	• too highly aggregated to be of any practical use

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
IIASA Energy Systems Program (ERP) International Institute for Applied Systems Analysis	The IIASA modelling exercise makes use of several separate but interconnected models which treat different aspects of energy systems. MEDEE 2 is one of the energy demand models in use, providing inputs to an energy supply and conversion model called MESSAGE. A macroeconomic model, MACRO, provides time trends of GNP and its components for MEDEE 2. The overall objective of the set of models (about 6 or 7 models in total) is to study the dynamics of national, regional, and global energy systems in some detail, and to examine the impact of energy systems on economics during a possible future period of energy transition (to the year 2030).	Description 1. a variety of IIASA publications describe all aspects of their system (see Bibliography).	• representative of state-of-the-art European energy models • environmental problems are explicitly considered in the supply model • the demand component relies on process analysis; thus not incorporating elasticities directly	• many of the IIASA models focus on global aspects; incorporating unnecessary detail for the project at hand • with respect to implementation in the Canadian context, the logistics problems, both from a geographical and language perspective, would be considerable

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Bechtel Energy Supply Planning Model (ESPM) J. Gallagher R. Zimmerman United States National Science Foundation, Energy Research Development Administration Department of Energy	ESPM calculates the direct resource requirements for capital, labour, materials and equipment, land and water, and operations and maintenance costs to construct, operate and maintain energy-related facilities at the national and regional level (given an energy supply and demand scenario).	Description 1. Gallagher, 1979. Applications Organizations currently using ESPM: 2. United States Dept. of Energy and Commerce. 3. United States Nat'l Academies of Science and Engineering. 4. Workshop on Alternative Energy Strategies (WAES). 5. World Coal Study (WOCO). 6. Electric Power Research Institute (EPRI). 7. International Institute of Applied Systems Analysis (IIASA). Review 8. Energy Modeling Forum "Coal in Transition" Study, 1979.	• highly detailed description of the physical resources used in energy production • straightforward structure and easily understood • ESPM has been adapted for use in other countries • has an ecological output side	• ESPM assumes a prespecified energy mix for the future; no optimization process is utilized at all • ESPM does simulate the effects of policy decisions but contains no specific decision-making criteria • operating data cannot be used to develop full energy facility operating costs

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Canadian Explor Model Government of Canada Department of Industry, Trade and Commerce Battelle Research Centre, Geneva	This Canadian version of the Explor system developed by Battelle is a macroeconomic input-output model which has been used for assessing the impacts of energy-related capital investment (e.g., pipelines), energy pricing studies, and energy conservation programs.	Description 1. Dept. of ITC, 1978. 2. Ziemba and Schwartz, 1980. 3. Watkins, 1980. Application - only within ITAC	• more detail on analysis of inter-industry flows and on disaggregated trade sector analysis than macroeconomic models such as Candide • Explor methology has been used in many other countries	• 'technological' detail is weak • no elasticity considerations • simulation conducted only in five-year increments • model is currently undergoing complete revision; 'new' model not expected to be in place until summer 1981 • input-output coefficients utilized in model are not publicly available for review
Fuller-Ziemba Model J. Fuller W. Ziemba University of British Columbia	The Fuller-Ziemba model is similar to ETA-MACRO model--a simple highly aggregated submodel of the macro-economy linked to a linear process submodel of extraction, processing, transportation and use of energy. It is a concave programming model which maximizes total discounted utility of consumption over the period 1975-2020 using a logarithmic utility function.	Description and Application 1. Ziemba, Schwartz, 1980. 2. Fuller and Ziemba, 1980. 3. Fuller, 1980.	• seemingly good structure and relatively high level of detail	• only considers two Canadian regions--one east and one west; model developers feel disaggregation to provincial level of detail extremely difficult • model equilibriates only on five year periods • unlike ETA-MACRO no macro-economic feedback link in the current structure

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Energy Technology Assessment Model (ETA-MACRO) A. Manne Electric Power Research Institute Stanford University	Integrated system of a neo-classical macroeconomy growth model and a dynamically specified nonlinear-programming energy sector model. Designed for analysis of long-run energy technology, resource allocation and policy alternatives. In ETA, the optimal levels of electric and non-electric energy are obtained by maximizing a net benefit function (a nonlinear programming problem). In ETA-MACRO the benefit function is replaced by a simple neoclassical growth model. The growth path is intended to represent market behaviour but it is obtained by choosing consumption to maximize a utility function.	Description 1. Ziemba and Schwartz, 1980 2. EPRI EA-592, 1977 3. EPRI PS-535, 1977 4. Pindyck, 1979 Application 5. IEEE, 1977 Review 6. Hughes, 1979 7. Hitch, 1977 8. DOE, 1979 9. COMEAS, 1978 10. CRA, 1978	• inexpensive to use • easy to interpret in analyzing broad future course of energy policy, the economy and technology • unlike DESOM has price elasticities	• the simplicity of ETA suggests that it is best suited for gaining insights only about the general picture; more highly aggregated than BULLDOG or Brookhaven models • substitution only between electric and non-electric energy • not regional in nature • cannot be used to analyze the interactions between energy, the supply of productive factors and interindustry composition of the economy • substitution among goods and productive factors is specified in terms of nested constant elasticity functions having restrictive features similar to those in the Wharton Annual Energy Model • coal transportation representation is nonexistent; ETA uses 'high' and 'low' cost coal • ETA's treatment of old and new energy-using capital is deficient

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Generalized Equilibrium Modelling Systems (GEMS) E. Cazalet Decision Focus Inc.	The conceptual framework for generalized equilibrium modelling is based on the twin foundations of decision analysis and coordinated decomposition. Implementation of the conceptual framework is in terms of a network of process models and an iterative solution algorithm. GEMS is not a model but a methodology that spawned a family of models (originating from the SRI-Gulf Model). Individual user groups have tended to tailor the basic framework to meet their own needs.	Description 1. Adler et al, 1979. 2. Cazalet, 1977. Application 3. Some of the more notable groups that are actively using GEMS (besides Decision Focus) are: Argonne National Laboratory Chase Manhatten Bank U.S. Department of Energy Electric Power Research Institute Lawrence Livermore Laboratories Stanford Research Institute Tennessee Valley Authority Review 4. Charles River Associates, 1978. 5. Brock and Nesbitt, 1977.	• this methodology combines the strengths of mathematical programming optimization with those of simulation; allowing different optimization criteria for each part of the energy system, but solving each time point successively (i.e. there exists no overall objective function) • its 'network' methodology would be amenable to dealing with the Canadian situation where inter-regional transportation and transmission issues are of vital importance • the accompanying software developed by Decision Focus is state-of-the-art, for instance, the user may select level of forecasting ability that might be descriptive of decision makers, ranging from myopic extrapolation to perfect foresight • credibility has been developed in this approach through extensive documentation and application	• it is not clear from the documentation that we have whether or not the Decision Focus GEMS is price sensitive on the demand side; in one of its offshoots (LEAP) demands are essentially exogenous, while in an early version of its predecessor (SRI-Gulf) end-use demands were made a function of price for a particular application • the introduction of explicit energy/economy interaction is underway, though not completely implemented

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Griffin Electricity Model J. Griffin Ford Foundation University of Houston	This model attempts to characterize the determinants and interrelations of electricity demands, fuel inputs, and electricity prices by using a simultaneous equations system. Note though that the publications utilized to review this model refer to work done by Griffin in the mid-seventies. Since then he has been instrumental in developing the 'pseudo-data approach' as utilized in conjunction with the Wharton Annual Energy Model. This method utilizes a detailed LP process model of the electricity industry to generate a single representative cost function which is input into the Wharton production technology. We have no documentation on this LP process model.	Description 1. Griffin, 1974 Review 2. Cowing and Smith, 1978	has links to the Wharton Long-Term and Industry Model; which provides the macroeconomic setting within which to simulate the model	• pure econometric structure, containing no detailed process analysis; hence its range of usefulness in policy analysis is limited • the model is best suited for simulation and forecasting over the 'intermediate' term, which the developer defines as 5 years • no regional disggregation, which is a severe limitation, considering that no 'national market' for electricity exists • no economic dispatch model for allocating current electricity generation between plant types; likewise an explicit system expansion component is lacking
Khyilicza Model E. Khyilicza	This is the most aggregate of the major energy/economy models. Production is organized around five factor inputs which combine to produce two outputs: energy and non-energy goods. Markets balance supply and demand in each successive time period. The parameters of this model have been empirically estimated.	Description 1. Ziemba and Schwartz, 1980. 2. EMF Report 1, 1977.	• provides a first order estimate of the potential flexibility of energy utilization (i.e., substitution across factor inputs is explicitly modelled using econometric relationships) • designed for long-term analysis	• the assumption of a single energy form implicitly suggests interfuel substitution • interaction of variables is strictly myopic, generally with instantaneous adjustment to price changes • lack of up-to-date published documentation

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
The IEA Energy Simulation Model (IEA) Institute for Energy Analysis, Oak Ridge Associated Universities United States, Federal Energy Administration	Designed to assess various long-term (1985 to 2040) research and development strategies which are likely to have an impact on the U.S. energy system. This model was intended to be the long-range counterpart of the PIES integration model.	Description 1. ORAU-125, 1976.	• environmental considerations are incorporated	• no explicit energy/economy interaction, thus making use for its designed purpose questionable • not regionally articulated • demand over time is simply based on assumed growth rates that are related to growth in GNP • no current public reference sources
Integrated Model for Energy Policy Analysis (IEPA) J. Helliwell University of British Columbia	Designed to evaluate the effects of different pricing, taxation and development strategies for Canadian natural gas, crude oil and synthetic oil.	Description 1. Watkins, 1980. 2. Ziemba and Schwartz, 1980. 3. McRae, 1979. 4. Helliwell, et al, 1979. Application - used by B.C. Government	• model pays special attention to energy trade, transportation, and oil and gas pricing • energy/economy interactions are currently being incorporated • calculates economic rents to producers, consumers, governments and as such is most useful for policy analysis	• no electric utility side pricing submodel • demand structure a bit simplistic relative to EMR-IFSDM • each end-use sector not treated independently
Integrated Forecasting Model (IFM) W. Balson S. Peck Energy Analysis and Environment Division, Electric Power Research Institute	The Integrated Forecasting Model is a national representation of U.S. energy markets. It is composed of sub-models provided by the EAL's supply and demand programs. There are 8 sub-models in the network.	Description 1. Balson and Peck, 1980. 2. EPRI, Demand '77, 1978. 3. EPRI, Supply '77, 1978. 4. EPRI, Long Range Forecasting Properties of state-of-the-art models of demand for electric energy, 1978. Application - Within EPRI	• the solution of the completely integrated model is much more powerful than the sum of the parts (individual solutions of sub-models) • demand side of model is very strong	• model as described in referenced publications no longer exists • EPRI is now a client of Decision Focus Inc. which maintains the model and operates it with their own software package • electricity sub-models have some weaknesses in pricing, load shape and plant mix areas

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Canadian Interfuel Substitution Demand Model (IFSDM) R. Sahi R. Erdmann Federal Department of Energy, Mines and Resources	Designed to model the various demands for energy so as to facilitate the projection of Canadian energy requirements. More specifically, 7 regions, 7 end-use sectors, and 4 fuel types are considered. The system recognizes the inter-dependence of energy consumption and other goods and services	Description 1. Sahi and Erdmann, in Ziemba and Schwartz, 1980. 2. E.M.R., 1979. 3. Sahi and Erdmann, 1978. 4. Erdmann, 1977. Application 5. Outside EMR, the IFSDM is currently utilized by a wide variety of users; for instance, Petro-Can, Alberta Energy Company, NOVA, Dome and Alberta Energy and Natural Resources. Review 6. A systematic documentation of the IFSDM code exists in unpublished form at the Canadian Energy Research Institute.	• high level of disaggregation • structurally designed for Canada • extensive accompanying data • relatively inexpensive to operate	• few actual driving variables • large sections of endogenous output are really exogenous data transfers • complex to make code modifications

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Kennedy-Nieneyer Model M. Kennedy L. Nieneyer Massachussetts Institute of Technology	Designed to model the impact of changes in energy supply on the U.S. economy at a aggregated (nine sector) level. Closely resembles the Hudson-Jorgenson accounting framework, but utilizes different behavioural assumptions.	Description 1. EMF Model Survey, 1978. 2. EMF Report 1, 1977. 3. EMF, WP 1.4, 1977.	• resource depletion effects are incorporated	• employs a production structure which implicitly assumes little flexibility in energy substitution; a fixed coefficient input-output matrix is used • given the aggregate level of GNP, consumption is determined via fixed shares • the interaction of variables is strictly myopic • lack of up-to-date published documentation

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Long-Term Energy Analysis Package (LEAP) Decision Focus, Inc. United States, Department of Energy	LEAP is a large-scale national energy-economic model which traces flows of energy and economic information between markets and market participants. It attempts to simulate competitive market processes through the interaction of estimated supply and demand functions. While based on a theoretical economic framework, LEAP introduces various types of lags and partial adjustment parameters in an effort to emulate complex real world systems. This model is a member of the GEMS family which is referred to elsewhere.	Applications 1. Annual Report to Congress, 1978. Review 2. Charles River Associates, 1980. 3. Department of Energy, 1979.	• the modelling system is extremely flexible • non-depletable energy sources are included • sponsored by the U.S. government, thus it is in the public domain	• capital, labour, foreign, and final demand variables are all exogenously specified • the assumption of fixed coefficient production (i.e., no input substitution in response to factor price changes) tends to over-estimate production costs • with respect to the electricity sector, no explicit economic dispatch criteria are applied to current generation sources

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Long-Term Interindustry Transactions Model (LITM) E. Hudson D. Jorgenson Electric Power Research Institute Ford Foundation Data Resources Inc.	The model system integrates econometric modelling with input-output analysis. It actually consists of two models: an energy-supply oriented macro-economic growth model and a variable-coefficient inter-industry model. Together these models provide a framework for the analysis of the general trends and pattern of long run economic growth as well as for the detailed examination of the composition of economic activity at any point on the growth path.	Description 1. Hudson and Jorgenson, 1974. Application 2. Hudson and Kimball, 1979. Review 3. Charles River Associates, 1979. 4. Brock and Nesbitt, 1977.	• the interindustry portion of this model is heavily energy orientated and due to the variable coefficient approach, considered state-of-the-art; these variable coefficients are functions of relative prices of the primary factors of production as well as the prices in all other sectors • the translog production functions employed enables the model to handle complex substitution and complementarity relationships among capital, labor, energy, and other inputs • its structure is amenable to integration with other more detailed energy supply models; for instance, BESOM, REM and MacAvoy-Pindyck have been linked to LITM	• less appropriate for handling intermediate term effects in a 'shock' situation • no explicit treatment of new technologies • the interaction of variables is myopic • constant returns to scale are assumed which ignores depletion and scale economy effects in individual energy industries

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
MacAvoy-Pindyck Natural Gas Model (M-P) P. MacAvoy R. Pindyck	Designed for the purpose of examining the effcts of alternative field price regulation policies on the natural gas industry. This model covers a broad spectrum of supply, demand, regulatory issues with respect to the natural gas industry as a whole. The supply process is detailed from exploration and discovery of reserves to the production phase, and finally to the distribution of gas intra and inter regionally. The model referred to here generally is the ENGS, which is not the most up-to-date version, but the only one well documented.	Description 1. MacAvoy and Pindyck, 1975. Review 2. Charles River Associates, 1979. 3. Mathematica, Inc. 1977. 4. Weri, 1977. 5. Pindyck, 1977.	• this was the first major simultaneous model of an energy industry and is still condidered by most reviewers the 'best' econometric model of the natural gas industry • highly disaggregated regionally (18 producing and 40 market regions) • well documented and extensively applied	• strictly a behavioural oriented econometric approach indicating limited explicit recognition of geological and engineering constraints • its emphasis concerns the policy debate over natural gas deregulation • reservoir decline effects are not incorporated

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Midterm Energy Forecasting System (MEFS) W. Hogan United States Department of Energy	The MEFS is a large scale, interdisciplinary system of models which provides DOE's midterm integrated energy forecasting and analysis capability (its predecessor had the name, Project Independence Evaluation System, PIES). It is a predictive and not a pure optimizing model (i.e., it does not contain an explicit objective function). MEFS has three major components: - nonlinear regional demand functions - piece-wise linear supply functions - an equilibrating mechanism which integrates the supply function with a linear approximation of the demand function and iterates on quantities and prices, recursively solving until an equilibrium solution is reached.	Description 1. Greenberg in Ziemba and Schwartz, 1980. 2. Department of Energy, 1979 3. A 15 volume set of documentation was published in 1976; it has since been updated and expanded. Application 4. MEFS provides the basis for the Energy Information Administration Annual Report to Congress Review 5. DeSouza, 1980 6. Brock and Nesbitt, 1977	• the system is consistently being enhanced and updated, with new operational versions available approximately every six months • all components of the system are publically available and extensively documented; no other model has undergone so much public scrutiny • certain individual components of the overall system are good; for instance, the integration submodel has remained essentially intact since its inception	• the MEFS is the world's largest general equilibrium model; this high level of disaggregation may be for some purposes an advantage, but we regard the accompanying structural complexities, massive data requirements and high operating costs as a disadvantage
Ontario Energy Demand System Ontario Government Ministry of Energy	The Ontario energy demand system simulates energy requirements at specified end-use and consuming sector levels and aggregates to energy demand for the residential, commercial, industrial and transportation sectors. Four separate energy demand models corresponding to the above sectors are linked by a fifth energy distribution and processing sector model.	Description 1. Watkins, 1980. 2. Ontario Government, 1979.	• better than average level of disaggregation	• technological change is not explicitly specified • interfuel substitutability is not explicitly specified • factor substitutability in the commercial and industrial sectors seems to be excluded

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
PILOT Economic Energy Model G. Dantzig S. Parikh Y. Connolly Electric Power Research Institute Stanford Research Institute	PILOT is a dynamically specified linear-programming model of energy supply, designed for long range assessment of new energy technologies, driven by a macro-economic demand model. It is specifically suited to study the impact of different energy supply conditions on the economy's capability to provide goods and services. Because of the orientation of its objective function towards maximizing consumer satisfaction PILOT is commonly referred to as a 'welfare equilibrium model'. The description of PILOT presented herein is derived from a 1978 publication (EPRI EA-626) and hence may be dated; on-going EPRI sponsored development is referred to there.	Description 1. Parikh, in Ziemba and Schwartz, 1980. 2. Stanford University, 1978. Application 3. EMF 1, 1977. Review 4. Department of Energy, 1979. 5. Charles River Associates, 1979.	• the ability to analyze the choice among supply technologies within each fuel category • energy sector includes primary resource depletion effects • interfuel and capital-energy substitution on the consumption side is under development	• too general a specification of the functioning of the economy and energy economy interaction • the fixed coefficient nature of the I-O matrix implies very restrictive assumptions with respect to substitution; although reference was made to the fact that a variable coefficient methodology was to be instituted in the future

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Reister-Edmonds General Equilibrium Energy Demand Model D. Reister J. Edmonds Institute for Energy Analysis, Oakridge	This system is a two sector general equilibrium energy demand model. The two sectors are energy and the rest of the economy. The model was developed to provide long-term (25-50 yr.) forecasts of energy demand and GNP and has been used to examine the impact of higher energy prices on GNP and the overall economy price level.	Description and Application 1. Hitch, 1977. 2. Lave in Hitch, 1977. 3. DOE, 1979.	• relatively easy to run; although serious doubts exist concerning its validity	• pricing component assumes average cost pricing for all energy sources and thus over-estimates energy use • model is similar to ETA-MACRO in its simplicity and very high degree of aggregation • model has no provision for interfuel substitution on demand side • assumes no further increase in relative energy prices after 1967 • counter intuitive results from the model have been observed • the DOE review of this model rejected it thoroughly and stated that the Reister-Edmonds model cannot be used in its present form

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Regionalized Electricity Model (REM) M. Baughman P. Joskow Electric Power Research Institute Energy Research and Development Administration Federal Energy Administration Ford Foundation National Science Foundation	Designed to examine the effects of a wide range of public policies on the electricity industry as a whole. A dynamic model of the electricity market, composed of quantitative descriptions of both the supply and demand side of the market that interact through the price of electricity.	Description 1. Foat and Protti, 1980. 2. Baughman, Joskow and Kamat, 1979. 3. Kamat, 1976. 4. Baughman and Joskow, 1974. Applications 5. Baughman, Joskow and Kamat, 1979. 6. Joskow and Rozanski, 1977. 7. Baughman and Joskow, 1977. 8. Joskow and Rozanski, 1976. 9. Joskow and Baughman, 1976. Review 10. Charles River Associates Inc., 1979. 11. MIT Model Assessment Group, 1978. 12. Cowing and Smith, 1978. 13. Jenkins, 1978. 14. Hoffman and Wood, 1976.	• it is a regionalized and disaggregated behavioral representation of the electricity industry • this model is currently the focus of intense EPRI sponsored development; also it has recently been linked to LTIM (Hudson and Kimball, 1979) • it has undergone extensive independent review and assessment with favorable results	• no feedback mechanism between level of fuel utilization and fuel prices • interregional transmission is not explicitly modelled

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Bechtel Corporation Regional Energy System for the Planning and Optimization of National Scenarios (RESPONS) P. Nagarvala G. Ferrell L. Oliver Energy Research and Development Administration	The Model deals with a regional U.S. energy system and is concerned with optimal flows and the utilization of different energy forms, with an emphasis on coal and coal-based energy sectors. The model permits interfuel substitutability, and includes a wide range of existing and developing technologies. It develops a methodology for the planning and analysis of complete energy systems from mining and extraction through energy conversion and transportation, environmental considerations, and energy demand. The model constructs and analyzes optimal systems of energy utilization based on regional descriptions of energy supplies, transportation networks, characteristics and availabilities of energy conversion facilities, environmental control techniques and energy demands.	Description and Application 1. P. J. Nagarvala et al, 1976. Review 2. EPRI EA-967, "Coal in Transition", 1979.	• endogenous representation of fuel choices by utilities • features relatively rapid and inexpensive simulation • definition of 'regions' for analysis can easily be varied	• non-coal energy systems are largely exogenous • opportunities for synthetic fuels are not articulated • energy transportation links are weak • 'public' version of RESPONS model has not been updated and is now several years old
Resources for the Future/Strategic Environmental Assessment System (RFF/SEAS) R. Ridker W. Watson A. Shapanka Environmental Protection Agency Resources for the Future	This is a system of interlinked models, the core of which is the University of Maryland's dynamic input-output model of the U.S. economy. Other models in the system involve energy-related physical and monetary variables, non-fuel minerals, transportation, and the environment.	Description 1. Hitch, 1977. 2. House, 1977.	• detailed environmental considerations are incorporated; in fact one focus of its design was to calculate pollution damages • suitable for long-term analysis (50 years)	• no explicit primary resource representation • the intertemporal values of all coefficients linking producing sectors with each other and with consumers are exogenously specified • lack of recent reference material

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Electric Energy Supply Model J. S. Rogers S. K. Choudhury National Research Council of Canada	This model utilizes a linear programming framework and it is addressed toward questions of the long term mix between the fossil and nuclear types of electric generation in Canada. It focuses on the effect that inter-regional transportation of coal or electric energy can have on the optimal mix.	Description and Application 1. Rogers and Choudhury, 1978. 2. Choudhury, 1977.	• very good on inter-regional transportation and transmission of energy	• model will be updated and revised during summer of 1981 • has not been applied by other than model developers • no construction lead time variability • five-year time periods rather than annual simulation • only three generating plant types specified • 'peaking' generating units are treated exogenously • regionally disaggregates into only four regions
Western Canada Energy Supply Model J. Rowse	This model is a static multi-regional linear programming representation of energy supply from Western Canada. The model was constructed as part of an effort to measure production labour requirements, regional wealth accrual, and economic resource rents associated with different energy resource development scenarios.	Description and Application 1. Rowse, 1979. 2. Ziemba and Schwartz, 1980.	• most economic patterns of production and transport of energy products can be determined independently of externally imposed restrictions--this makes inefficiency in energy supply system more obvious • model appears to operate in a straightforward and efficient manner	• assumes perfectly competitive operation of energy markets • minimal representation of energy resource processing • not being utilized or extended at the moment • no multiple time period framework • while oil and gas supply side is captured geographically, representation of electricity conversion is deficient

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
SRI-Gulf Energy Model E. Cazalet Gulf Oil Stanford Research Institute	A detailed, regionally articulated network model of energy supply and demand. It was originally applied to analyses of synthetic fuels development strategies for Gulf Oil Company.	Applications 1. Stanford University, 1978. 2. Kopelman and Nesbitt, 1977. Reviews 3. CONEAS, 1978. 4. Charles River Associates, 1978. 5. Brock and Nesbitt, 1977.	• the dynamic specification, sophisticated market-clearing mechanism, and flexible modular organization encouraged its use as a prototype for an energy sector integrating model; the GEMS family of models have since emanated from this source	• although Gulf has maintained this model and improved the data base, the original modellers have since left to substantially revise and extend the basic methodology; this leads us to believe that the SRI-Gulf model is not the state-of-the-art representative of this type of modelling approach
Total Energy Resource Analysis (TERA) Mathematica, Inc. American Gas Association	Designed to assist in evaluating policy issues relative to the supply and demand of natural gas. TERA is broken down into 7 interacting sub-models: demand forecasting, energy market share, supply forecasting, price structure, regulation and prices, supply-demand interaction model, gas industry. The latter is the most detailed, consisting of financial requirements, energy efficiency, pollution, peak demands and storage capacity.	Description 1. American Gas Association, 1979. Application 2. Ball, Sweeney and Weyant, 1980.* Review 3. Mathematica Incorporated, 1977.	• each component sub-model is a simulation module that combines econometric and structural considerations; it is designed in a flexible structure so as to allow a wide variety of studies using all, or only relevant parts, of the entire model system • the model, at regular intervals, undergoes maintenance and updating	• other primary energy sources besides natural gas are only referenced in the context of interfuel substitution; supply functions for these competitive fuels are not explicitly modelled, hence there is no feedback effect between usage and price levels • an imbalance exists between the sophistication of individual component parts of the model system; for instance the offshore submodel is highly disaggregated geographically, while the onshore submodel is in essence a national representation

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Brookhaven Time-Stepped Energy System Optimization Model (TESOM) A. Kydes J. Rabinowitz Brookhaven National Laboratories	TESOM is a national energy system model which reflects uncertainties in the energy planning process since it assumes imperfect foresight with respect to future supplies, demands, prices and available technologies. TESOM was conceived and developed to provide an improved automated simulation capability and an alternative decision making tool to MARKAL.	Description 1. Kydes in Zeimba and Schwartz, 1980. 2. Kydes and Pasingwitz, 1980. Application 3. EMF, Coal in Transition, 1977.	• in addition to the strengths outlined in BESOM and DESOM, TESOM has a market penetration mechanism not existent in the former two models--this mechanism allows for the simulation of the gradual penetration of new technologies into the energy market • annual simulation in an optimization framework • other advantages are outlined in section 3.2 of text	• data requirements are large
The Informetrica Model (TIM - energy sector) P. Jacobson M. McCracken Informetrica Ltd.	The Informetrica Model is a redevelopment of the Economic Council of Canada's CANDIDE model. Integrated into this macroeconomic model is an energy submodel encompassing demand for energy, prices, taxes and royalties.	Description 1. Zeemba and Schwartz, 1980. 2. Watkins, 1980.	• strong links both to and from the macroeconomy • detailed tax and royalty specification • policy rules well delineated	• assumes utilization of existing electricity plants to be exogenous • no primary resource representation • no regional disaggregation • supply and demand equate via residual balancing items

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Wharton Annual Energy Model (WAEM) L. Klein Electric Power Research Institute	WAEM is a macroeconomic income-determination (post-Keynesian) model with an embedded input-output system. The structure of this model is very similar to its ancestor, the Wharton Annual Macroeconomic Model, but with respecified input-output tables and expansion of the energy sector detail.	Description 1. Wharton E.F.A., Inc., 1979 Application 2. The model was used to look at the macroeconomic impacts of implementing the Carter energy plan. Review 3. MIT Energy Lab, 1979. 4. Charles River Associates, 1979. 5. U.S. Department of Energy, 1979.	• a high degree of industrial disaggregation • its predecessor is well documented and tested, although this 'energy' version is in development stage (as of 1979) • satellite models are integrated with the main framework to provide industry specific detail • with respect to the utility sector a methodology has been developed and implemented which integrates detailed engineering process models with conventional econometric cost functions as contained in WAEM; this methodology is referred to as the 'pseudo-data' approach	• the model is predominantly demand-oriented, with only limited attention given to supply-side considerations and to long-run market clearing mechanisms: therefore the model is probably restricted to near and medium-term analysis • constant elasticity is assumed in production functions for substitution between materials inputs, capital, and labor • the endogenous input-output coefficients are responsive to price, but not to the extent apparent in LITM

MODEL-SPECIFIC EVALUATION - CANADIAN MACRO MODELS

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
AERIC Conference Board in Canada	AERIC is a medium size quarterly econometric model of the Canadian economy and is used primarily for forecasting and impact studies. The model is currently being expanded and will contain the 1971 Statistics Canada input-output table. There is an associated regional model based on data created and collected by the Conference Board. In some sectors of the model provincial estimates are based on the national model forecasts. Energy is treated on a very aggregative basis.	Description 1. Conference Board in Canada, 1980. Review 1. W. Paul Jenkins, and Lloyd E. Kenward, 1977	• the model provides a regional disaggregation	• the model is simulated for no more than 5 years, the provincial model for two years only • has fixed input-output coefficients • model would need to be modified in order to link to an energy model
CANDIDE 2.0 Economic Council of Canada	CANDIDE 2.0 is a large scale annual econometric model of Canada. The model features substantial industrial detail, well articulated financial and trade sectors and numerous government policy options.	Description 1. Economic Council of Canada, 1979. Application 1. Economic Council of Canada, 1979. 2. Economic Council of Canada, 1980	• great wealth of industrial detail should facilitate linking to energy supply/demand models	• has no regional dimension • large complex structure requires extensive experience to use effectively • input-output coefficients are static • database contains some unpublished and arbitrarily estimated series

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPERS(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Canadian Welfare Equilibrium Model (CWEM) D. Quon Alberta Research Council Energy and Natural Resources University of Alberta	CWEM is a large scale inter-temporal clairvoyant, optimizing market equilibrium energy-economy model. The macroeconomic sector is a neoclassical growth model with variable input-output coefficients. Capital, labour and energy factor proportions are variable ex ante but fixed ex post.	Description D. Quon, undated	• being supply driven should produce better long run simulations • input-output coefficients are variable • energy/economy interaction is explicit	• has no regional disaggregation • produces quinquennial output • model is currently under construction
DRI Macro Model Data Resources Canada Inc.	DRI's model is a medium size annual econometric model used to produce forecasts and impact studies. It combines a National Accounts framework with Statistics Canada's 1971 input-output table. The model is designed to link with DRI's own energy model. DRI has models of the B.C., Alberta and Ontario economies as well.		• although normally only run for 10 years into the future, the model has been simulated for 25 year span • some regional information is available • links to energy model are in place	• input-output table has fixed coefficients and does not produce feedback effects on income and employment

MODEL-SPECIFIC EVALUATION

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
Helliwell Macro Model J. Helliwell R. McRae University of British Columbia University of Calgary Bank of Canada	This is a small, annual econometric model of the Canadian economy, designed to provide a two way link with the Helliwell Energy Model. The model gives a special role to energy. Energy and capital are bundled together and combine with labour services to produce output. The energy intensity of capital is variable ex ante but fixed ex post.	Description 1. Helliwell and McRae, 1980.	• articulation of the supply side should make for better long-run forecasts • specifies dynamic adjustment mechanism for capital-energy bundle • small size (50 equations) should make it relatively easy to use and understand	• contains no regional dimension • deals only with primary energy • model is not yet developed; only some equations are specified and none are estimated
RDX2 J. Helliwell R. Sparks, et al Bank of Canada	RDX2 is a medium size quarterly econometric model used primarily to assess the impact of fiscal and monetary policies. The model has detailed financial, government, personal income tax and trade sectors but the private sector is not as well developed. Output is determined by a production function capturing the influence of physical capital, labour and long run technical progress.	Description 1. T. Maxwell, 1978. 2. Bank of Canada, 1976. 3. Bank of Canada, 1977. 4. John F. Helliwell, Gordon R. Sparks, Frederick W. Gorbet, Harold T. Shapiro, Ian A. Stewart, and Donald R. Stephenson, 1971. Application 1. Leo de Bever and Tom Maxwell, 1979. Review 1. John F. Helliwell, T. Maxwell and M. E. L. Weslander, 1979. 2. W. Paul Jenkins and Lloyd R. Kenward, 1977.		• quarterly model is only useful for short term forecasting • has no regional dimension • energy model links are limited

MODEL DEVELOPER(S) SPONSOR(S)	SYSTEM DESCRIBED	PUBLISHED COMMENTARY	FOR PURPOSES OF CEA MODEL SURVEY	
			ADVANTAGES	DISADVANTAGES
The Informetrica Model (TIM - macro) P. Jacobson M. McCracken Informetrica Ltd.	TIM is a large scale, annual econometric model of Canada used for forecasting and impact studies. The model contains a wealth of industrial detail and a well articulated trade sector. The model is built on a National Accounts framework and contains the Statistics Canada 1971 input-output model. A detailed energy demand model (energy supply is exogenous) has been fully integrated with TIM. Associated with TIM is a model of provincial construction activity.	Description 1. Informetrica Ltd., 1980. Application 1. Informetrica Ltd., 1980b.	• links between the energy model and the macro model are well articulated • some provincial indicators are available • model is regularly simulated for 20 year period	• input-output table has fixed coefficients • large size and complex structure requires extensive experience for effective use
TRACE J. Sawyer Institute for Policy Analysis, University of Toronto	TRACE is an annual medium size econometric model of Canada. Total output is determined by the interaction of a final demand schedule for domestic goods and an aggregate suply schedule. It is based on the national accounts and is used primarily for short run forecasting and policy analysis.	Description 1. Nanda K. Choudhry, Yehuda Kotowitz, John A. Sawyer, and John L. Winder, 1972. 2. Institute for Policy Analysis, 1977. Application 1. David K. Foot, James E. Pesando, John A. Sawyer, John W. L. Winder, 1977. 2. J. L. Carr, G. V. Jump, and J. A. Sawyer, 1976. 3. John A. Sawyer, 1979. Review 1. David K. Foot and John A. Sawyer, 1979.		• linking of energy model would require reworking of the macro model • has no regional disaggregation

BIBLIOGRAPHY

Adar, Joseph, and Manne, A. S. "Integrated Supply-Demand Projects for Energy Growth." EPRI PS-535-SR. Palo Alto, California: Electric Power Research Institute, July 1977.

Adler, R.; Cazalet, E. G.; Haas, S. M.; Marshalla, R. A.; Nesbitt, D. M.; and Phillips, R. L. The DFI Generalized Equilibrium Modeling System. Palo Alto, California: Decision Focus Incorporated, December 1979.

Agnew, Malcolm; Schrattenholzer, L.; and Voss, A. "A Model for Energy Supply Systems Alternatives and their General Environmental Impact." WP-79-6. Laxenburg, Austria: International Institute for Applied Systems Analysis, January 1979.

Ahn, Byong-Hun. "Computation of Market Equilibria for Policy Analysis: The Project Independence Evaluation." Ann Arbor, Michigan: University Microfilms International, 1979.

Aigner, Dennis J., and Poirier, Dale J. "Electricity Demand and Consumption by Time-of-Use: A Survey." EPRI EA-1294. Palo Alto, California: Electric Power Research Institute, December 1979.

Alberta. Energy and Natural Resources/Alberta Research Council. Conference Papers. Edmonton: Government of Alberta, December 1978.

Alberta Gas Trunk Line Company Limited. "In the Matter of the Public Hearing on Alberta's Requirements of Energy and Energy Resources for the Year 1977 through 2006." Proceeding No. 770048. Calgary: Alberta Gas Trunk Line Company Limited, August 1977.

American Gas Association. TERA Volume II: Onshore Gas and Oil Supply Model. Arlington, Virginia: American Gas Association, 1979.

Askin, Bradley A. How Energy Affects the Economy. Lexington, Mass.: Lexington Books, 1978.

Askin, Bradley A.; Farman, R. L.; Lagace, G. L.; and Malloy, A. J. "An Empirical Analysis of the Relationship between Energy and the Economy." Journal of Energy and Development 2 (Spring 1977): pp. 252-256.

Askin, Bradley A., and Kraft, John. Econometric Dimensions of Energy Demand and Supply. Lexington, Mass.: Lexington Books, 1976.

Ball, Ben C.; Sweeney, J. L.; and Weyant, J. P. "U.S. Oil and Gas Supply Summary Report." Working Paper EMF 5.4. Stanford, California: Energy Modeling Forum, Stanford University, February 1980.

Bank of Canada. "The Equations of RDX2 Revised and Estimated to 4Q72." Technical Report. Ottawa: Bank of Canada, 1976.

_____. "Sectoral Analysis of RDX2 Estimated to 4Q72." Technical Report. Ottawa: Bank of Canada, 1977.

Barouch, E., and Kaufman, G. M. "A Probabilistic Model of Oil and Gas Discovery." Working Paper. Cambridge, Mass.: Sloan School of Management, Massachussetts Institute of Technology, June 1975.

Baughman, Martin L.; Joskow, P. L.; and Kamat, D. P. Electric Power in the United States. Cambridge, Mass.: The MIT Press, 1979.

Baumol, William J. Economic Theory and Operations Analysis. 2nd ed. Englewood Cliffs, N.J.: Prentice-Hall Inc., 1965.

Beaujean, J.-M., and Charpentier, J.-P., eds. A Review of Energy Models: No. 4 - December 1976. RR-78-12. Laxenburg, Austria: International Institute for Applied Systems Analysis, July 1978.

Beaujean, J.-M.; Charpentier, J.-P.; and Nakicenovic, N. "Global and International Energy Models: A Survey." Annual Review of Energy 2 (1977): pp. 153-170.

Bechtel National Inc. Projected Annual Resource Requirements at the National and Regional Level. Prepared for the U.S. Department of Commerce, Office of Ocean, Resource and Scientific Policy Coordination. Washington: U.S. Department of Commerce, 1979.

Behling, David; Marcuse, W.; Swift, M.; and Tessmer, R. G., Jr. "A Two-level Iterative Model for Estimating Interfuel Substitution Effects." Upton, New York: Brookhaven National Laboratory, March 1975.

Behling, David J., Jr. "A Dynamic Systems Analysis of the Relation between Energy and the Economy." Upton, New York: Brookhaven National Laboratory, July 1976.

Behling, David J., Jr.; Cherniavsky, E. A.; Hoffman, K. C.; and Jorgenson, D. W. "Overview of Technological-Economic Models for Energy Policy Analysis." Presented at Workshop on Energy Strategies. Laxenburg, Austria: International Institute for Applied Systems Analysis, May 18, 1977.

Behling, David J., Jr., and Dullien, Robert. "A Combined Linear Programming and Econometric Systems Analysis of the Relation between Energy, Growth and the Economy." Upton, New York: Brookhaven National Laboratory, 1977.

Behling, David J., Jr.; Dullien, Robert; and Hudson, Edward. "The Relationship of Energy Growth to Economic Growth under Alternative Energy Policies." Upton, New York: Brookhaven National Laboratory, March 1976.

Bernanke, Ben, and Jorgenson, Dale W. "The Integration of Energy Policy Models." Computer and Operations Research 2 (1975): pp. 225-249.

Berndt, Ernst R.; Morrison, C. J.; and Watkins, G. C. "Dynamic Models of Energy Demand: An Assessment and Comparison." Resources Paper No. 49. Vancouver: Department of Economics, University of British Columbia, February 1980.

Brock, Horace W., and Nesbitt, Dale M. "Large Scale Energy Planning Models: A Methodological Analysis." Menlo Park, California: Decision Analysis Group, Stanford Research Institute, May 1977.

Brookhaven National Laboratory. Dynamic Energy System Optimization. Palo Alto, California: Electric Power Research Institute, May 1979.

Canada. Department of Energy, Mines and Resources. Energy Demand Modelling System. Ottawa: Department of Energy, Mines and Resources, Economics and Policy Analysis Sector, January 1979.

_____. Department of Industry, Trade and Commerce. Overview Canadian Explor Model (CEM 1). Ottawa: Department of Energy, Mines and Resources, Macro Economic Structural Analysis Group, March 1978.

_____. Economic Council of Canada. Sixteenth Annual Review: Two Cheers for the Eighties. Ottawa: Economic Council of Canada, 1979.

_____. Economic Council of Canada. Candide 2.0 Model Description. Volumes 1 and 2. Ottawa: Economic Council of Canada, October 1979.

_____. Economic Council of Canada. "A Climate of Uncertainty." Seventeenth Annual Review. Ottawa: Economic Council of Canada, 1980.

Charles River Associates Inc. "Long Range Forecasting Properties of State-of-the-Art Models of Demand for Electric Energy." EPRI EA-211. Palo Alto, California: Electric Power Research Institute, December 1976.

_____. Review of Large Scale Energy Models. EPRI EA-968. Palo Alto, California: Electric Power Research Institute, January 1979.

_____. "Design for Coal Supply Analysis System." EPRI EA-1086. Palo Alto, California: Electric Power Research Institute, May 1979.

_____. "CRA/EPRI Coal Market Analysis System, Volume 1: Overview." EPRI EA-907. Palo Alto, California: Electric Power Research Institute, July 1979.

_____. "CRA/EPRI Coal Market Analysis System, Volume 2: Technical Background." EPRI EA-907. Palo Alto, California: Electric Power Research Institute, July 1979.

_____. The Economic Foundations of LEAP Model 22C. Prepared for Oak Ridge National Laboratory. Boston, Mass.: Charles River Associates Inc., September 1980.

Charpentier, Jean-Pierre. A Review of Energy Models: No. 1 - May 1974. Laxenburg, Austria: International Institute for Applied Systems Analysis, October 1974.

_____. A Review of Energy Models: No. 2 - July 1975. Laxenburg, Austria: International Institute for Applied Systems Analysis, October 1975.

Choudhry, Nanda K.; Kotowitz, Y.; Sawyer, J. A.; and Winder, J. W. L. The TRACE Econometric Model of the Canadian Economy. Toronto: University of Toronto Press, 1972.

Choudhury, S. K. "A Regional Model for Planning the Expansion of the Electric Generation and Long Distance Transmission System in Canada (1980-2010): A Linear Programming Approach." Master's Thesis. Toronto: Department of Industrial Engineering, University of Toronto, 1978.

Clark, C. E., Jr.; Haas, S. M.; Nesbitt, D. M.; Oman, D. B.; and Phillips, R. L. Modeler's Guide to Building Energy-Economy Models Using the Generalized Equilibrium Modelling System and the Model Data Management System. Palo Alto, California: Decision Focus Incorporated, July 1979.

Conference Board in Canada. "Medium Term Model." (Mimeographed). Ottawa: Conference Board in Canada, 1980.

Corr, J. L.; Jump, G. V.; and Sawyer, J. A. "The Operation of the Canadian Economy Under Fixed and Flexible Exchange Rates: Simulation Results from the TRACE Model." The Canadian Journal of Economics 9 (February 1976).

Cowing, Thomas G., and Smith, Kerry V. A Survey of Econometric Models of the Supply and Cost Structure of Electricity. Prepared for Electric Power Research Institute. Binghamton, New York: Department of Economics, State University of New York, March 1978.

Daniel, Terrence E., and Goldberg, Henry M. "Dynamic Equilibrium Energy Modelling: The Canadian BALANCE Model." Edmonton: Department of Finance and Management Science, University of Alberta, March 1980.

Data Resources Inc. "User's Guide to the Datatapes from EPRI Projects." EPRI EA-235, vol. 3. Palo Alto, California: Electric Power Research Institute, December 1976.

_____. "The DRI Canadian Energy Model: Technical Description." Lexington, Mass: Data Resources Inc., 1980.

Data Resources of Canada. "Canadian Energy Service: Proposal and Technical Discussion." Lexington, Mass.: Data Resources Inc., 1979.

DataMetrics Limited. "Projections of Energy Demand Using a Modelling Approach, 1980-1990." Prepared for NOVA, An Alberta Corporation. Calgary: DataMetrics Limited, September 1980.

_____. "An Assessment of the Department of Energy, Mines and Resources Model of Energy Demand." Prepared for NOVA, An Alberta Corporation. Calgary: DataMetrics Limited, December 1980.

De Bever, Leo, and Maxwell, Tom. "An Analysis of Some of the Dynamic Properties of RDX2." The Canadian Journal of Economics 12 (May 1979).

de Buen, Victor. "An Energy Model of British Columbia." Presented at IEEE Power Engineering Society Summer Meeting, Vancouver, July 15-20, 1979.

De Souza, Glenn. "International Energy Models in the Public Sector: A Critical Guide." The Journal of Energy and Development 5 (1980): pp. 95-106.

_____. "Mid-Range Energy Forecasting System: Structure, Forecasts and Critique." Energy Systems and Policy 4, nos. 1 and 2 (1980): pp. 5-24.

Decision Focus, Inc. "Integrated Analysis of Load Shapes and Energy Storage." EPRI EA-970. Palo Alto, California: Electric Power Research Institute, March 1979.

_____. "Users Guide to the Over/Under Capacity Planning Model." EPRI EA-1117. Palo Alto, California: Electric Power Research Institute, July 1979.

_____. "The Integrated Forecasting Model." EPRI EA-1119. Palo Alto, California: Electric Power Research Institute, August 1979.

_____. "Integrated Models for R & D Planning." EPRI EA-1462. Palo Alto, California: Electric Power Research Institute, July 1980.

Dux, C. D.; Krohm, G. C.; and VanKuiken, J. C. "Modeling Long-term Coal Production with the Argonne Coal Market Model." ANL/AA-13. Argonne, Illinois: Argonne National Laboratory, August 1977.

Economic Dynamics, Inc. "Supply Models with Feedback Features, Volume 1: Executive Summary." EPRI EA-1357. Palo Alto, California: Electric Power Research Institute, March 1980.

_____. "Supply Models with Feedback Features, Volume 2: A Review of Adaptive Economics Modelling." EPRI EA-1357. Palo Alto, California: Electric Power Research Institute, March 1980.

_____. "Supply Models with Feedback Features, Volume 3: Modelling Production, Investment, and Technological Change in the Coal Sector--A Methodological Review and Evaluation." EPRI EA-1357. Palo Alto, California, Electric Power Research Institute, March 1980.

Economics Research Group Ltd. "Dynamic Models of the Industrial Demand for Energy." EPRI EA-580. Palo Alto, California: Electric Power Research Institute, November 1977.

Electric Power Research Institute. "Proceedings of the Workshop on Modeling the Interrelationships between the Energy Sector and the General Economy." WS 76-51. Edited by J. Daniel Khazoom. Palo Alto, California: Electric Power Research Institute, January 1976.

_____. Supply 77: EPRI Annual Energy Supply Forecasts. EA-634-SR. Palo Alto, California: Electric Power Research Institute, May 1978.

Energy Modeling. Edited by Milton F. Searl. Washington: Resources for the Future, Inc., March 1973.

_____. Papers Presented at a Special Workshop Organised by the U.S. National Science Foundation and the Energy Research Unit, Queen Mary College, London. London: IPC Business Press Ltd., 1974.

Energy Modeling Forum. "Energy and the Economy." EMF Report 1, vol. 1. Stanford, California: Energy Modeling Forum, Stanford University, September 1977.

_____. "Aggregate Elasticity of Energy Demand." EMF Report 4, vol. 1. Stanford, California: Energy Modeling Forum, Stanford University, August 1980.

Energy Policy Modeling: United States and Canadian Experiences. Vols. 1 and 2. Edited by W. T. Ziemba, S. L. Schwartz and E. Koenigsberg. Boston: Martinus Nijhoff Publishing, 1980.

Faucett, Jack, Associates. "Power Shortage Costs and Efforts to Minimize: An Example." EPRI EA 1241. Palo Alto, California: Electric Power Research Institute, December 1979.

Feick, J. E., and McConaghy, D. J. "The Relative Economics of Recovering and Upgrading Alberta's Hydrocarbon Resources." Journal of Canadian Petroleum Technology 15:19-26, 1976.

Fletcher, A. L., and Associates. "An Evaluation of the Pseudo-Data Approach." EPRI EA-1108. Palo Alto, California: Electric Power Research Institute, July 1979.

_____. "Cost Uncertainty in Programming Models of Electricity Supply." EPRI EA-1636. Palo Alto, California: Electric Power Research Institute, November 1980.

Flint, Robert; Martin, Thomas; and Oman, Donna B. User's Guide to the DFI Model Data Management System (MDMS). Palo Alto, California: Decision Focus Incorporated, January 1980.

Foat, Kenneth D., and Protti, Gerard J. "A Regionalized Electricity Model: Preliminary Analyses." Working Paper 80-2. Calgary: Canadian Energy Research Institute, April 1980.

Foot, David K.; Pesando, J. E.; Sawyer, J. A.; and Winder, J. W. L. The Ontario Economy 1977-1987. Toronto: Ontario Economic Council, 1977.

Foot, David K., and Sawyer, J. A. "Some Dynamic Properties of the TRACE Model." The Canadian Journal of Economics 12 (May 1979).

Fraser, John T. "Documentation of the Brookhaven Energy I-O and I-O/BESOM Linkage." Upton, New York: Brookhaven National Laboratory, August 1978.

Fromholzer, D., and Parikh, S. C. "Driving Variables, Scenario Definitions, and Individual Model Exceptions." EMF WP 1.2. Stanford, California: Energy Modeling Forum, Stanford University, June 1977.

Fuller, J. D. "A Long-Term Energy Policy Model for Canada." PhD Thesis. Vancouver: Department of Mathematics, University of British Columbia, September 1980.

Fuller, J. D., and Ziemba, W. T. "A Long-Term Energy Policy Model for Canada." Working Paper No. 701. Vancouver: Faculty of Commerce and Business Administration, University of British Columbia, 1980.

Fuss, Melvyn A. "The Demand for Energy in Canadian Manufacturing." Journal of Econometrics 5 (1977): pp. 89-116.

Gallagher, Michael J., and Zimmerman, Ralph G. "Engineering a Transition to Coal." Natural Resources Forum 3 (1979): pp. 379-400.

Gass, Saul I. "Evaluation of Complex Models." Computers and Operations Research 4 (1977): pp. 27-35.

_____. "A Procedure for the Evaluation of Complex Models." Proceedings of the First International Conference on Mathematical Models. St. Louis: University of Missouri, 1977.

_____. "Assessing Ways to Improve the Utility of Large-Scale Models." College Park, Md.: College of Business and Management, University of Maryland, 1979.

Gass, Saul I., ed. "Validation and Assessment Issues of Energy Models." Proceedings of a Workshop Held at the National Bureau of Standards, Gaithersburg, Maryland, January 1979.

Gass, Saul I.; Hoffman, K. L.; Jackson, R. H. F.; Joel, L. S; and Saunders, P. B. "Interim Report on Model Assessment Methodology: Documentation Assessment." NBSIR 80-1971. Washington: U.S. Department of Commerce, June 1980.

_____. The NBS Energy Model Assessment Project: Summary and Overview. NBSIR 80-2128. Washington: U.S. Department of Commerce, June 1980.

Gass, Saul I., and Joel, L. S. "Concepts of Model Confidence." NBSIR 80-2053. Washington: Operations Research Division, U.S. Department of Commerce, June 1980.

General Electric Company. "Regional Electric Utility Operations Model, Volume 1: Technical Report." EPRI EA-897. Palo Alto, California: Electric Power Research Institute, December 1978.

_____. "Generation System Reliability Analysis for Future Cost/Benefit Studies." EPRI EA-958. Palo Alto, California: Electric Power Research Institute, January 1979.

Goettle, R. J., IV; Cherniavsky, E. A.; and Tessmer, R. G., Jr. "An Integrated Multi-Regional Energy and Interindustry Model of the United States." Upton, New York: Brookhaven National Laboratory, May 1977.

Goettle, R. J., IV; Hudson, E. A.; and Lukachinski, J. "A Comparative Assessment of Energy-Economy Interactions." Upton, New York: Brookhaven National Laboratory, December 1978.

Gordon, Richard L. "Economic Analysis of Coal Supply: An Assessment of Existing Studies." EPRI 335-1, vol. 1. Palo Alto, California: Electric Power Research Institute, February 1976.

Greenberger, Martin, and Richels, Richard. "Assessing Energy Policy Models: Current State and Future Directions." Annual Review of Energy 4 (1979): pp. 467-500.

Griffin, James M. "The Effects of Higher Prices on Electricity Consumption." The Bell Journal of Economics 5 (Autumn 1974): pp. 515-539.

Hafele, W. "Second Status Report of the IIASA Project on Energy Systems." RR 76-1. Laxenburg, Austria: International Institute for Applied Systems Analysis, 1976.

Hafele, W., and Manne, A. S. "Strategies for a Transition from Fossil to Nuclear Fuels." RR 74-7. Laxenburg, Austria: International Institute for Applied Systems Analysis, June 1974.

Halvorsen, Robert. Econometric Models of U.S. Energy Demand. Lexington, Mass.: D. C. Heath and Company, 1978.

Harvard University. "Combined Energy Models." EPRI EA-1420. Palo Alto, California: Electric Power Research Institute, May 1980.

Helliwell, J. F.; Maxwell, T.; and Waslander, H. E. L. "Comparing the Dynamics of Canadian Macromodels." The Canadian Journal of Economics 12 (May 1979).

Helliwell, J. F., and McRae, R. N. "Output, Potential Output, and Factor Demands in an Aggregate Open Model Economy with Energy and Capital Bundled Together." Mimeograph, October 25, 1980.

Helliwell, J. F.; Sparks, G. R.; Gorbet, F. W.; Shapiro, H. T.; Stewart, I. A.; and Stephenson, D. R. The Structure of RDX2: Parts 1 and 2. Staff Research Study. Ottawa: Bank of Canada, 1971.

Hirst, Eric, and Carney, Janet. "The ORNL Residential Energy-Use Model: Structure and Results." Land Economics 55 (August 1979): pp. 319-333.

Hoffman, Kenneth C., and Jorgenson, Dale W. "Economic and Technological Models for Evaluation of Energy Policy." Bell Journal of Economics 8 (Autumn 1977).

Hoffman, Kenneth C., and Wood, David O. "Energy System Modeling and Forecasting." Annual Review of Energy 1 (1976): pp. 423-453.

Hogan, W. W., and Manne, A. S. "Energy Economy Interactions. The Fable of the Elephant and the Rabbit?" EMF WP 1.3. Stanford, California: Energy Modeling Forum, Stanford University, July 1977.

Hogan, W. W., and Parikh, S. C. "Comparison of Models of Energy and the Economy." EMF WP 1.4. Stanford, California: Energy Modeling Forum, Stanford University, May 1977.

House, Peter W., and McLeod, John. Large-Scale Models for Policy Evaluation. New York: John Wiley and Sons Inc., 1977.

Hudson, Edward A., and Behling, David J., Jr. "Energy Conservation Policies: Possibilities, Mechanisms and Impacts." Upton, New York: Brookhaven National Laboratory, December 1978.

Hudson, Edward A., and Jorgenson, Dale W. "Tax Policy and Energy Conservation." In Econometric Studies of U.S. Energy Policy. Edited by Dale W. Jorgenson. Amsterdam: North-Holland Publishing Co., 1976.

Hudson, Edward A., and Kimball, Christian E. Economic Growth in the Future. Cambridge, Mass.: Dale W. Jorgenson Associates, December 14, 1979.

Hughes, William R. "National and Regional Energy Models." Growth and Change. January 1979, pp. 92-103.

ICF Incorporated. "Coal and Electric Utilities Model Documentation." Draft. Washington: ICF Incorporated, May 1980.

Informetrica Limited. The Canadian Economy to 2000: Assumptions and Summary Post-Workshop I-80 Forecast. Ottawa: Informetrica Limited, June 12, 1980.

_____. TIM Model Book. Ottawa: Informetrica Limited, October 1980.

Institute for Policy Analysis. TRACE Mk IV E: An Annual Econometric Model of the Canadian Economy. Reference Manual for TRACE Mk IV E. Toronto: Institute for Policy Analysis, University of Toronto, 1977.

International Institute for Applied Systems Analysis. Proceedings of the Workshop on Energy Demand. Edited by William D. Nordhaus. Laxenburg, Austria: International Institute for Applied Systems Analysis, May 22-23, 1975.

_____. Methods of Systems Analysis for Longterm Energy Developments. Edited by Yuri Kononov. Laxenburg, Austria: International Institute for Applied Systems Analysis, March 1977.

Jenkins, Paul W., and Kenward, Lloyd R. "The Comparative Ex Post Forecasting Properties of Several Canadian Quarterly Econometric Models." Technical Report. Ottawa: Bank of Canada, January 1977.

Jenkins, R. Taber. "Evaluation of System Expansion and Electricity Supply Model Used in the Baughman-Joskow Regional Electricity Model." Prepared for Electric Power Research Institute. Chattanooga, Tennessee: Tennessee Valley Authority, February 1978.

Johnston, J. Econometric Methods. 2nd ed. New York: McGraw-Hill Book Company, 1972.

Kamat, Dilip P. "Documentation of the Regionalized Electricity Model." Austin, Texas: Center for Energy Studies, The University of Texas, December 1976.

Kaufman, G.; Balcer, Y.; and Kruyt, D. "A Probabilistic Model of Oil and Gas Discovery." Studies in Geology. Vol. 1, AAPG, 1975.

Kaufman, G. M. Statistical Decision Theory and Related Techniques in Oil and Gas Exploration. Englewood Cliffs, N. J.: Prentice-Hall, 1962.

_____. "Statistical Analysis of the Size Distribution of Oil and Gas Fields." 1965 Symposium on Petroleum Economics and Evaluation. AIME, 1965.

Kaufman, G. M., and Bradley, P. G. "Two Stochastic Models Useful in Petroleum Exploration." Arctic Geology Memoir No. 19. AAPG, 1973.

Kline, D., and Swift, M. "A Catalog of Energy Models." EMF OP 1.0. Stanford, California: Energy Modeling Forum, Stanford University, June 1978.

Kononov, Yuri. "Modeling of the Influence of Energy Development on Different Branches of the National Economy." RR 76-11. Laxenburg, Austria: International Institute for Applied Systems Analysis, October 1976.

Kononov, Yuri, and Por, A. "The Economic Impact Model." RR 79-8. Laxenburg, Austria: International Institute for Applied Systems Analysis, October 1979.

Kopelman, Jay B., and Nesbitt, Dale M. "The Economic Costs of a Nuclear Moratorium." Energy 2 (1977): pp. 33-43.

Koreisha, Sergio. "The Limited of Energy Policy Models." Energy Economics. April 1980.

Kydes, A. S., and Rabinowitz, J. "Overview and Special Features of the Time-Stepped Energy System Optimization Model (TESOM)." Prepared for U.S. Department of Energy. Upton, N.Y.: Associated Universities, Inc., September 1980.

Lapillonne, Bruno. "MEDEE 2: A Model for Long-Term Energy Demand Evaluation." RR 78-17. Laxenburg, Austria: International Institute for Applied Systems Analysis, November 1978.

Lawrence Berkeley Laboratory and Operations Research Center, University of California. "A Quadratic Programming Analysis of Energy in the United States Economy." Palo Alto, California: Electric Power Research Institute, December 1975.

Logistics Management Institute. "An Executive Summary of Volume 1 of the Project Independence Evaluation System (PIES)." Prepared for U.S. Department of Energy. Washington: Energy Information Administration, October 1978.

MacAvoy, Paul W., and Pindyck, Robert S. The Economics of the Natural Gas Shortage (1960-1980). Amsterdam: North-Holland Publishing Co., 1975.

McCracken, M. C. An Overview of Candide Model 1.0. Candide Project Paper No. I. Ottawa: Economic Council of Canada, February 1973.

Manne, Alan S. "ETA: A Model for Energy Technology Assessment." The Bell Journal of Economics 7 (Autumn 1976).

Manne, Alan S.; Richels, R. G.; and Weyant, J. P. "Energy Policy Modeling: A Survey." Operations Research 27 (January-February 1979).

Marchetti, C., and Nakicenovic, N. "The Dynamics of Energy Systems and the Logistic Substitution Model." RR 79-13. Laxenburg, Austria: International Institute for Applied Systems Analysis, December 1979.

Mathematic Incorporated, Mathtech Division. "A Comparative State-of-the-Art Assessment of Gas Supply Modeling." EA-201. Palo Alto, California: Electric Power Research Institute, February 1977.

Maxwell, T. "A Primer on RDX2." Bank of Canada Review, January 1978, pp. 3-10.

Missner, Susan; Dintersmith, W.; and Sweeney, J. L. "A Selection of Possible Studies for the Energy Modeling Forum." EMF Planning Paper 2.2. Stanford, California: Energy Modeling Forum, Stanford University, May 1979.

Massachusetts Institute of Technology. The FEA Project Independence Report: An Analytical Review and Evaluation. Cambridge, Mass.: Policy Study Group, MIT Energy Laboratory, May 1975.

_____. "Independent Assessment of Energy Policy Models." EPRI EA-1071. Palo Alto, California: Electric Power Research Institute, May 1979.

_____. "Papers Presented at a Conference on Energy Prices, Inflation and Economic Activity." MIT-EL 79-065 WP. Cambridge, Mass.: MIT Energy Laboratory, November 1979.

Mathtech, Incorporated. "Comparative State-of-the-Art Assessment of Oil Supply Modeling." EPRI EA-609. Palo Alto, California: Electric Power Research Institute, June 1978.

Modeling Energy-Economy Interactions: Five Approaches. Edited by Charles J. Hitch. Research Paper R-5. Washington: Resources for the Future Inc., 1977.

Nagarvala, P. J.; Ferrell, G. C.; and Oliver, L. A. Regional Energy System for the Planning and Optimization of National Scenarios (RESPONS). Prepared for the United States Energy Research and Development Administration. San Francisco: Bechtel Corporation, June 1976.

Nakicenovic, N. "Software Package for the Logistic Substitution Model." RR 79-12. Laxenburg, Austria: International Institute for Applied Systems Analysis, December 1979.

National Research Council. Energy Modeling for an Uncertain Future. Supporting Paper 2. Washington: National Academy of Sciences, 1978.

Neal, F., and Shone, R. Economic Model Building. London: The MacMillan Press Ltd., 1976.

Neri, John A. "An Evaluation of Two Alternative Supply Models of Natural Gas." The Bell Journal of Economics 8 (Spring 1977).

Pennsylvania State University. "Economic Analysis of Coal Supply: An Assessment of Existing Studies." Research Project 335, Key Phase Report. Prepared for EPRI. Palo Alto, California: Electric Power Research Institute, May 1975.

_____. "Economic Analysis of Coal Supply: An Assessment of Existing Studies." EPRI EA-496, vol 2. Palo Alto, California: Electric Power Research Institute, July 1977.

Pindyck, R. S. "The Regulatory Implications of Three Alternative Econometric Supply Models of Natural Gas." The Bell Journal of Economics 5 (Autumn 1974): pp. 633-645.

Pindyck, R. S., ed. Advances in the Economics of Energy and Resources Volume 2: The Production and Pricing of Energy Resources. Greenwich, Connecticut: JAI Press Inc., 1979.

Prince, J. Philip. Enhanced Oil Recovery Potential in Canada. Study No. 9. Calgary: Canadian Energy Research Institute, March 1980.

Protti, Gerard J., and McRae, Robert N. The Impact of Rate Structure Change on Electricity Demand: A Case Study of Calgary Power Limited. Study No. 10. Calgary: Canadian Energy Research Institute, April 1980.

Quon, Don. "A Canadian Energy-Economy Policy Model." Edmonton: Department of Chemical Engineering, University of Alberta, 1980.

Quon, Don; McConaghy, D.; and Wong, S. "Analysis of Some Alternative Natural Gas Scenarios Using AERAM." Presented at the 30th Canadian Society for Chemical Engineering Conference, Edmonton, October 20, 1980.

Research for Growth & Transfer, Inc. "An Integration Methodology for Energy Supplies and Demands." EPRI EA-1633. Palo Alto, California: Electric Power Research Institute, November 1980.

Resource Planning Associates, Inc. "Inclusion of Cogeneration in Electric Utility Models." EPRI EA-1504. Palo Alto, California: Electric Power Research Institute, September 1980.

Rogers, J. S., and Choudhury, S. K. "Planning Interregional Electric Energy Supply in Canada (1980-2010): A Linear Programming Approach." Proceedings of Sixth Power Systems Computation Conference, Darmstadt, Germany, August 21-25, 1978.

Rowse, John. "A Model of Energy Supply from Western Canada." Discussion Paper No. 344. Kingston, Ont.: Institute for Economic Research, Queen's University, May 1979.

_____. "Economic Benefits of Co-operative Power Supply Expansion." Calgary: The University of Calgary, December 1979.

Sawyer, John A. "Prospects and Policies for Economic Growth." Economic Policy Review 1:3 (1979).

Schmitt, R. W.; BenDaniel, D. J.; and Manne, A. S. "An Econometric Analysis of Energy Over the Next 75 Years." IEEE Transactions on Power Apparatus and Systems. Vol. PAS-96, No. 4, July/August 1977.

Stanford University. "ETA-MACRO: A Model of Energy-Economy Interactions." EA-592. Palo Alto, California: Electric Power Research Institute, December 1977.

———. "Stanford Pilot Energy/Economic Model." EPRI EA-626, vol. 2. Palo Alto, California: Electric Power Research Institute, May 1978.

———. "Coal in Transition." EPRI EA-967. Palo Alto, California: Electric Power Research Institute, February 1979.

Stanford University. Department of Operations Research. "Stanford Pilot Energy/Economic Model." EA-626, vol. 1. Palo Alto, California: Electric Power Research Institute, May 1978.

Sweeney, J. L., and Weyant, J. P. "The Energy Modeling Forum: Past, Present and Future." EMF PP 6.1. Stanford, California: Energy Modeling Forum, Stanford University, May 1979.

———. "Meeting Summary: Energy Modeling Forum Senior Advisory Panel." EMF Planning Paper 2.3. Stanford, California: Energy Modeling Forum, Stanford University, June 1979.

Systems Control, Inc. "Analytical and Demonstration Experience with Changing Load Profile." EPRI PS-1293. Palo Alto, California: Electric Power Research Institute, December 1979.

Tessmer, Raymond G., Jr., and Sanborn, Yasuko. "EAG-5, Expanded 110 Sector, Energy Input-Output Model." Upton, New York: Brookhaven National Laboratory, December 1975.

Theil, Henri. Principles of Econometrics. Toronto: John Wiley and Sons Inc., 1971.

Truong, Thuan-Van, and Nguyen, The-Hiep. "Un Modele de Production Optimale d'Energie pour le Quebec." Cahier 8004. Quebec: Department of Economics, Universite Laval, April 1980.

United States. Department of Commerce. Six-Year Review of Energy by the Harvard University School of Business. Hearing before the Subcommittee on Energy Conservation and Supply at the Ninety-sixth Congress, First Session, 1979. Washington, D. C.: U.S. Government Printing Office, 1979.

———. Department of Commerce. Validation and Assessment Issues of Energy Models. NBS-SP-569. Washington, D.C.: National Bureau of Standards, January 1979.

———. Department of Commerce. Utility and Use of Large-Scale Mathematical Models. NBS-SP-534. Washington, D.C.: National Bureau of Standards, May 1979.

———. Department of Energy. "Applied Analysis Modeling Capacity Survey, 'Models Index.'" Technical Memorandum. Washington, D.C.: Energy Information Administration, February 22, 1978.

_____. Department of Energy. Survey of the Research into Energy-Economy Interactions. Vol. 1: Survey. Vol. 2: Annotated Bibliography. Washington, D.C.: Energy Information Administration, April 1979.

_____. Department of Energy. Applied Analysis Model Summaries. Technical Report. Washington, D.C.: Energy Information Administration, May 1979.

University of California at Berkeley. "Correction of End Effects in Energy Planning Models." EPRI EA-1231. Palo Alta, California: Electric Power Research Institute, November 1979.

University of Houston. "Energy Supply and Demand Properties from Engineering Process Models." EPRI EA-1568. Palo Alto, California: Electric Power Research Institute, October 1980.

Univeristy of Michigan. "Evaluation of the Federal Energy Administration's Load Management and Rate Design Demonstration Projects." EPRI EA-1152. Palo Alto, California: Electric Power Research Institute, August 1979.

University of Oklahoma. Regional Power Systems Planning; A State of the Art Assessment. DOE/RA/29144-01. Washington: U.S. Department of Energy, October 1980.

University of Texas at Austin. "Assessment of the Effect of Uncertainty on the Adequacy of the Electric Utility Industry's Expansion Plans, 1983-1990." EPRI EA-1446. Palo Alto, California: Electric Power Research Institute, July 1980.

Watkins, G. C. "Econometric Models of Industrial Energy Demand: A Dynamic Formulation." Calgary: Dat.metrics Limited, 1980.

_____. "Briefing Paper: Energy Supply and Demand Policy Models in Canada." Conference on Policy Issues in Energy Self-Sufficient Economies at Different Stages of Industrialization, Mexico City, September 4-7, 1980.

Weinberg, Alvin M. "Limits to Energy Modeling." Oak Ridge, Tenn.: Institute for Energy Analysis, Oak Ridge Associated Universities, September 1979.

Wharton E. F. A., Inc. "The Wharton Annual Energy Model: Development and Simulation Results." EPRI EA-1115. Palo Alto, California: Electric Power Research Institute, July 1979.

Whittle, Charles E.; Reister, D. B.; Silver, E. G.; Weinhold, J. F.; Ahmed, S. B.; Davitian, H. E.; MacPherson, H. G.; and Perry, A. M. The IEA Energy Simulation Model. Oak Ridge, Tenn.: Institute for Energy Analysis, Oak Ridge Associated Universities, January 1976.

Zimmerman, Martin B. "Modeling Depletion in a Mineral Industry: The Case of Coal." The Bell Journal of Economics 8 (Spring 1977): pp. 41-65.

_____. "Estimating a Policy Model of U.S. Coal Supply." MIT-EL 77-042WP. Cambridge, Mass.: MIT Energy Laboratory, December 1977.

CANADIAN ENERGY RESEARCH INSTITUTE

PUBLICATIONS

Studies

No. 1 The Availability of Capital to Fund the Development of Canadian Energy Supplies. J. R. Downs. November 1977 (Price $3.00, 109 pages) ISBN 0-920522-00-9.

No. 2 The Industrial Demand for Oil and Gas in Ontario. DataMetrics Limited. March 1978 (Price $3.00, 119 pages) ISBN 0-920522-01-7.

No. 3 The Effects of Rising Energy Costs on Canadian Industry. Anthony P. Ellison. April 1979 (Price $3.00, 62 pages) ISBN 0-920522-02-5.

No. 4 Potential Markets for Thermal Coal in Canada, 1978-2000: Summary and Conclusions. Canadian Resourcecon Limited. June 1979 (Price $3.00, 27 pages) ISBN 0-920522-03-3.

No. 5 Energy in Canada: Review and Outlook to 1995. W. Brent Friedenberg. July 1979 (Price $3.00, 140 pages) ISBN 0-920522-04-1.

No. 6 Energy Policy and the Balance of Payments: An Outline of the Issues. T. L. Powrie. July 1979 (Price $3.00, 61 pages) ISBN 0-920522-05-X.

No. 7 Oil and Gas Finding Costs. Russell S. Uhler. September 1979 (Price $3.00, 75 pages) ISBN 0-920522-06-8.

No. 8 Energy Use in Canada in Comparison With Other Countries. Z. Charles Slagorsky. October 1979 (Price $3.00, 91 pages) ISBN 0-920522-07-6.

No. 9 Enhanced Oil Recovery Potential in Canada. J. Philip Prince. March 1980 (Price $10.00, 332 pages) ISBN 0-920522-09-2.

Conclusions and Policy Implications from Enhanced Oil Recovery Potential in Canada, Study No. 9. J. Philip Prince. March 1980 (Price $3.00, 32 pages) ISBN 0-920522-10-6.

...continued

No. 10 The Impact of Rate Structure Change on Electricity Demand: A Case Study of Calgary Power Limited. Gerard J. Protti and Robert N. McRae. April 1980 (Price $10.00, 182 pages) ISBN 0-920522-11-4.

Overview and Summary from The Impact of Rate Structure Change on Electricity Demand: A Case Study of Calgary Power Limited. Gerard J. Protti and Robert N. McRae. April 1980 (Price $3.00, 14 pages) ISBN 0-920522-12-2.

No. 11 The Impact of a Sharp Oil Price Increase. G. E. Angevine. June 1980. (Price $10.00, 122 pages) ISBN 0-920522-13-0.

No. 12 Benefits and Costs of Oil Self-Sufficiency in Canada. J. A. Dawson and Z. C. Slagorsky. February 1981. (Price $10.00, 97 pages) ISBN 0-920522-15-7.

Client Research Reports

No. 1 Models for Energy Policy Analysis: A Survey. Kenneth D. Foat and Gerard J. Protti. July 1981. (Price $10.00, 121 pages) ISBN 0-920522-16-5.

Working Papers

78-1 Drilling and Field Construction Costs in the Canadian Petroleum Industry. Gordon M. Engbloom, Confer Consulting Limited. January 1978 (Price $3.00, 83 pages).

78-2 Some Supply Price Estimates for Synthetic Crude Oil in Canada. Z. Charles Slagorsky. April 1978 (Price $3.00, 42 pages).

78-3 Past and Future Energy Costs in the Canadian Economy. Anthony P. Ellison. April 1978 (Price $5.00, 136 pages).

78-4 Canadian Electric Utility Industry Costs, 1960-1990. Gerard J. Protti. May 1978 (Price $10.00, 218 pages).

78-5 Enhanced Oil Recovery Potential in Canada - A Methodological Preview. J. Philip Prince. June 1978 (Price $10.00, 184 pages).

78-6 Regional Energy and Production Data for Canadian Manufacturing Industries: 1962-74. Robert N. McRae and Alan R. Webster. July 1978 (Price $5.00, 106 pages).

78-7 Regional Demand for Energy by Canadian Manufacturing Industries. Robert N. McRae. October 1978 (Price $5.00, 132 pages).

...continued

79-1 An Input-Output Analysis of the Effects of Rising Energy Costs on Canadian Industries. Anthony P. Ellison. April 1979 (Price $10.00, 246 pages).

79-2 Potential Markets for Thermal Coal in Canada, 1978-2000. Canadian Resourcecon Limited. June 1979 (Price $15.00, 321 pages).

79-3 Inter-City Comparisons of Canadian Household Energy Costs. Darcy-Gail Ackerman. June 1979 (Price $3.00, 77 pages).

80-1 Government Incentives in Canada's Petroleum Industry. W. B. Friedenberg, Z. C. Slagorsky, and A. J. Walsh. March 1980 (Price $3.00, 43 pages).

80-2 A Regionalized Electricity Model: Preliminary Analyses. Kenneth D. Foat and Gerard J. Protti. April 1980 (Price $3.00, 61 pages).

80-3 Alternative Future Supplies of Oil in Canada and Their Costs. Z. Charles Slagorsky. May 1980 (Price $3.00, 36 pages).

80-4 Prospects for Reduced Oil Consumption in Canada. W. B. Friedenberg and A. J. Nixon. May 1980 (Price $3.00, 34 pages).

Conferences

Markets for Canadian Uranium. Proceedings of a Seminar Held on October 25, 1979, Calgary, Alberta. (Price $10.00, 89 pages) ISBN 0-920522-08-4.

Annual Report

Annual Report of the Board of Directors for the Period April 1, 1980 to March 31, 1981.